Appendix F1 – Assessment of Controls (Watershed Restoration Assessment)

WHEEL CREEK

WATER CHEMISTRY MONITORING

YEAR 11 REPORT

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1.0 INTRODUCTION

Harford County conducts monitoring in the Wheel Creek watershed to evaluate the benefits of various improvement projects, including stormwater pond retrofits and stream restorations. Wheel Creek has been identified as the County's priority watershed to satisfy National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit-required monitoring.

Wheel Creek watershed drains 435 acres consisting of high density residential and commercial land uses in the headwaters, and medium and low density residential and forest land uses in the remainder. The streams in the watershed have been altered by changes in hydrology associated with recent urbanization and historical agricultural land use. Imperviousness has increased to 27% in the past three decades of development (Harford County DPW 2008). In total, eight individual construction projects have been completed in tributaries and stormwater facilities in the watershed during 2012 to 2017 in an effort to improve instream chemical, biological, and physical conditions.

Monitoring to assess the effectiveness of the restoration effort in the Wheel Creek watershed to comply with the requirement of the MS4 permit has been ongoing since 2009. Harford County contracted with Versar, Inc., to conduct water chemistry and continuous flow monitoring. Previously, monitoring was performed in conjunction with requirements associated with the Chesapeake and Atlantic Coastal Bays 2010 Trust Fund stream restoration initiative, which included funding for the restoration projects and continuous flow, biological, and physical monitoring performed by Maryland Department of Natural Resources (DNR). Monitoring requirements for the Trust Fund stream restoration initiative have since been satisfied. Baseflow water chemistry monitoring, previously undertaken by County staff, has been conducted by Versar from 2018 to the present. Continuous flow monitoring near all three of the water chemistry monitoring stations has been conducted by Versar from June 2016 to the present. Biological and physical monitoring have been conducted by KCI Technologies beginning in 2019. Geomorphological assessments have been conducted annually since 2010, first by the County and subsequently by Versar. United States Geological Survey (USGS) operates a stream flow gauging station near the mouth of Wheel Creek (USGS Station 0158175320) and a stage level gauging station and tipping bucket rain gauge in Atkisson Reservoir (USGS Station 01581753).

This report documents the water chemistry monitoring activities undertaken by Harford County, Versar, and USGS, and summarizes the data obtained from July 1, 2020 to June 30, 2021. The activities included capturing eight wet weather events, monthly baseflow monitoring, and continuous flow rate monitoring in the Wheel Creek watershed. Of note, the final wet weather event of FY2021 initiated on June 30, 2021, counting towards the permit requirements for Harford County, but continued until July 2, 2021. As such, discharge and chemical results fall within the next permit year and are excluded from this assessment; results from this storm will be included in the Year 12 report. An assessment of long-term pollutant concentration trends and reduction by the restoration projects is also presented.

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2.0 STUDY AREA AND STUDY DESIGN

Wheel Creek forms a portion of the Atkisson Reservoir Watershed and resides within the Bush River Basin. It consists of approximately 435 acres of watershed, 2.2 linear stream miles, and five stormwater management facilities. Four stream reaches were targeted for restoration and four stormwater facility retrofits were planned in the drainage area (Harford County DPW 2008). Restoration and retrofit activities began in 2012 and continued through April 2017 (Table 2-1). Pre-restoration and post-restoration data will be used to assess performance of portions of the stream restoration and stormwater BMP retrofit projects as well as for the overall watershed. The current monitoring period represents the fourth full year of post-restoration data collection and analyses.

Table 2-1. Timeline of restoration and retrofit projects in Wheel Creek watershed (M. Dobson pers. comm.)

Construction Projects	Start Date	Completion Date
Gardens of Bel Air (Pond A)	September 8, 2012	December 20, 2012
Calverts Walk (UMS-1)	January 14, 2013	April 4, 2013
Festival of Bel Air (Pond C)	May 12, 2015	August 7, 2015
Country Walk 1A (Pond D)	September 21, 2015	December 11, 2015
MMS-5, MB-4, MB-1	December 7, 2015	February 26, 2016
Water Quality Facilities (4)	December 7, 2015	March 18, 2016
Lower Wheel Creek	September 19, 2016	March 2017
Country Walk 1B (Pond E)	December 2016	April 2017

The water chemistry monitoring study design employs before and after conditions assessments corresponding to comparisons of pre- and post-restoration and retrofit phases. The initiation, termination, and duration of the phases vary by station and the schedule of restoration construction.

Three long-term automated water chemistry sampling and flow logging stations were established at Stations WC002, WC003, and WC004 (Figure 2-1). Station WC004 is located on the middle branch, immediately downstream of the stormwater retrofit at Festival Shopping Center (Point C). Stations WC003 and WC004 bracket completed stormwater retrofits at Pond D and Pond E along the middle branch. Station WC002 is located on the mainstem and water chemistry data collected there will provide an overall assessment of the benefits of retrofit and restoration projects in upstream tributaries (Figure 2-2). Baseflow monitoring took place at three stations along the Wheel Creek main stem and tributaries (WC002, WC003, and WC004).

Figure 2-1. Wheel Creek Watershed long-term water chemistry monitoring stations

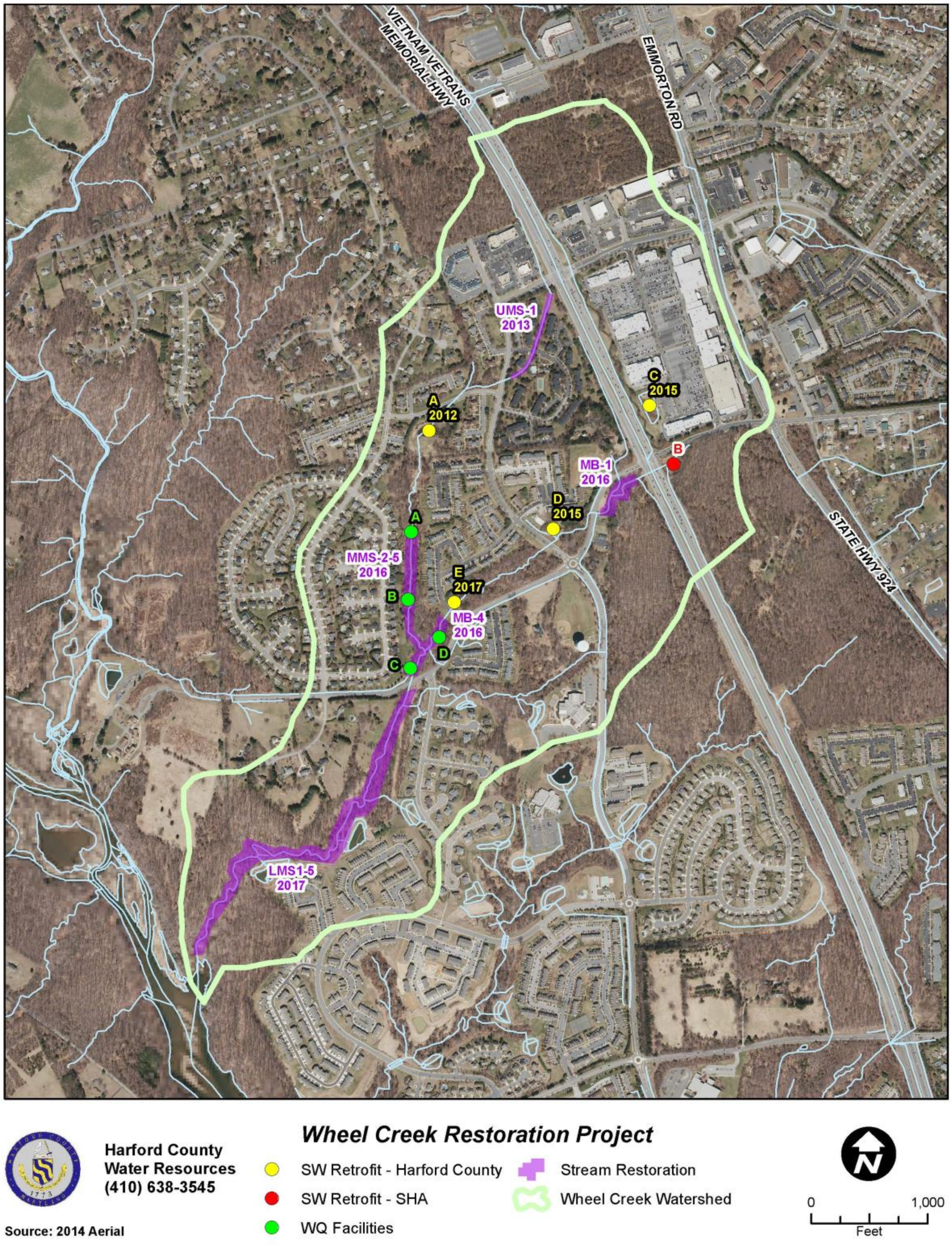

Figure 2-2. Stream restoration and stormwater retrofit sites in Wheel Creek watershed.

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3.0 METHODS AND MATERIALS

3.1 STORMFLOW MONITORING

Fixed, automated stormflow monitoring and long-term flow logging stations were situated at the following locations:

- WC002 – Wheel Creek mainstem at Wheel Road
- WC003 – Middle branch at Cinnabar Lane
- WC004 – Middle branch off Wheel Court

Stormflow samples were collected by Versar staff using American Sigma 900Max samplers at Stations WC002, WC003, and WC004 working in conjunction with ISCO 4230 bubbler flow meters. Automated sampling equipment was installed in September 2010 at Station WC002 and Station WC003 and mid-October 2010 at Station WC004. During storms, bubbler flow meter tubing and carriers were secured at the downstream end of culverts at Station WC002 and Station WC003 while the bubbler tube at Station WC004 was secured instream. Automated samplers contained 24, one-liter polypropylene bottles and were programmed to start at a specific time (based on the storm forecast) by field staff to sample the rising, peak, and falling limbs of the storm on a time-paced basis. Separate composite samples were created on a discharge volume-proportional basis to represent the rising, peak, and falling limbs of the stream hydrograph.

Eight events were monitored between July 1, 2020 and June 30, 2021 (Table 3-1); storm characteristics for the June 30, 2021 overlapped with FY2022 and will therefore be presented in the subsequent reporting year. Event rainfall duration was calculated from the first to the last measurable amounts of rain that triggered the tipping mechanism within the rain gauge. Antecedent dry time was calculated by determining the time interval between the initiation of rainfall for the monitored event and the cessation of rainfall for the prior event. Qualifying storm events required a minimum of 24 hours where there had been less than 0.03 inches total accumulated rainfall.

Flow rate during monitored storm events was determined using Manning's equations specific to each outfall pipe at Stations WC002 and WC003 and by rating curve at Station WC004. The rating curve at Station WC004 was prepared using directly-measured velocities, over a range of stages, along a stream channel cross-section (Appendix B). Versar field staff measured velocity and channel depth using a Marsh-McBirney Flowmate 2000 flowmeter, with sensor attached to a graduated wading rod (Jones and Hage 2011). Automated storm sampling procedures are described in fuller detail in the project's Quality Assurance and Quality Control Document (Corbin et al. 2021). The duration of a storm event was recorded as the time of elevated flow (Appendix A). Stations WC003 and WC004 were found to have flow levels above baseflow longer than Station WC002 for several monitored storm events. These prolonged periods of elevated flow for these stations were possibly due to the stormwater ponds upstream of them detaining and releasing water over an extended period of time, where the continued discharge from these stormwater ponds contributed to flows above baseflow in the smaller upstream station systems where channels are narrower, and flows elevate easier.

Stream water samples were tested for the analytes listed in Table 3-2. Since May 2013, samples were tested for an expanded suite of analytes that included turbidity and chloride. Analytes with multiple detection limits are presented as a range in Table 3-2.

Table 3-1. Statistics for monitored storms, July 2020 – June 2021

Date	Rainfall Total (in.)	Rainfall Duration (hr.)	Antecedent Dry Time (hr.)
3-Aug-20	3.89	28.0	70.2
11-Sep-20	0.34	13.0	15.9*
12-Nov-20	2.15	36.0	232.3
14-Dec-20	0.98	22.0	166.3
16-Feb-21	0.81	20.0	198.2
19-Mar-21	0.73	40.0	402.8
28-May-21	1.58	32.0	43.1

Rainfall recorded by primary onsite rain gauge at Station WC002
* Local weather stations recorded no precipitation ahead of storm event program, and stream conditions were at baseflow level, so crew did not anticipate dry time below 24-hour threshold when deploying for this event

Table 3-2. Parameters, methods, detection limits, and water quality criteria for Wheel Creek monitoring

Parameter	Analytical Method	Reporting Limit (mg/L)	Method Detection Limit (mg/L)	MD Freshwater Criteria[a]		EPA Recommended Ambient Water Quality Criteria[b] (mg/L)
				Acute (µg/l)	Chronic (µg/l)	
BOD-5	SM 5210 B	1-2	0.2-1			
Nitrate + Nitrite	SM 4500 NO3F	0.1-0.2	0.02-0.1			0.69 (Total N)[c]
Total Kjeldahl Nitrogen	SM 4500 NorgD	0.5	0.08-0.3			
Orthophosphate	SM 4500 PE	0.02-0.05	0.009-0.02			
Total Suspended Solids	SM 2540D	2-5	2-5			
Copper	EPA 200.8	0.001-0.004	0.0002-0.0005	13	9	
Lead	EPA 200.8	0.001-0.002	0.00006-0.0006	65	2.5	
Zinc	EPA 200.8	0.005-0.02	0.001-0.005	120	120	
Chloride[d]	EPA 300.0	5-50	5-50			860 (acute) 230 (chronic)
Ammonia	SM 4500 NH3H	0.1-0.3	0.04-0.05			
Total Phosphorus	SM 4500 PB&E	0.05-0.1	0.01-0.1			0.03656
Hardness	SM 2340C	10	10			
Turbidity	HACH 10258	0.01-1	0.01-0.5			
Total Petroleum Hydrocarbons	EPA 1664A	5	5			
E. coli (reported as MPN/100 ml)	SM 9223B	1	1			

(a) Values from COMAR 26.08.02.03-2 (undated).
(b) U.S. EPA 2000. Recommended criteria are derived from the 25th percentile of concentrations in all streams in the ecoregion.
(c) Total nitrogen concentration is the sum of total Kjeldahl nitrogen and combined nitrate plus nitrite.
(d) U.S. EPA 1988. Ambient Water Quality Criteria for Chloride.

Storm event mean concentrations (EMCs) were calculated individually for each storm by obtaining the concentration of each pollutant, weighted according to limb discharge volume. Limb discharges were determined by plotting the portion of the storm hydrograph represented by the composite sample and integrating under the curve using Flowlink software. For TPH and *E. coli*, which were collected by grab during irregular occasions during stormflow, a simple average concentration without flow weighting was calculated ("greater than" *E. coli* results were set to the numerical result).

Estimated pollutant loading values for each storm were determined by multiplying the storm EMCs by the total storm discharge in cubic feet. Total storm discharge was determined by plotting the storm hydrograph and integrating under the curve using Flowlink software.

3.2 BASEFLOW MONITORING

Baseflow monitoring was completed monthly by Versar staff. Grab samples were collected at the locations listed below.

- WC002 – Wheel Creek mainstem at Wheel Road
- WC003 – Middle branch at Cinnabar Lane
- WC004 – Middle branch off Wheel Court

3.3 LONG-TERM FLOW RATE LOGGING

Long-term flow rate logging was conducted at Stations WC002, WC003, and WC004 described above. Maryland DNR installed Solinst flow loggers in 2012 and maintained them through June 2016, at which point Versar assumed responsibility for monitoring and maintenance. Versar conducted monthly site inspections, logger downloads, and baseflow discharge measurements between July 2020 and June 2021. Storm discharge measurements were also collected whenever possible to verify the rating curve at each station.

During the winter months, the Solinst flow loggers were removed from service to prevent damage to the sensors due to icing. During these periods, ISCO 4230 bubbler flow meters were installed to capture level data while the Solinst loggers were offline.

Complete flow series for each station were compiled from the Solinst and ISCO logger data. Staff performed quality control on the level time series to remove any anomalous data (e.g., resulting from manipulation during Solinst data offloads). Levels were corrected to reflect observed staff gauge readings, and linear drift corrections were applied to the time series at each station to compensate for logger drift. A rating curve was established at each of the three logging stations to convert each logger's level data to flow rate (Appendix B).

3.4 RAINFALL LOGGING

Rainfall was recorded by an Onset HOBO electronic, tipping-bucket rain gauge situated in an open area near Station WC002. The gauge was downloaded and maintained by Versar field staff and is the primary gauge used for storm event rainfall totals. Daily rainfall recorded by the gauge is presented in Appendix C. Rainfall records from USGS' Atkisson Reservoir gauge (0.8 miles away to the SW), the secondary rainfall recorder, were used to supplement the onsite data in cases where onsite gauge data were unavailable due to power interruptions or mechanical failures. When the onsite rain gauge experienced a malfunction, a local Weather Underground station (www.wunderground.com; Bel Air South Station) was used for storm event rainfall totals since it is closer to the monitoring stations than the USGS gauge; the USGS rain gauge represents the official totals used for comparison over the entire duration of the year.

3.5 DETERMINATION OF STORM EVENT POLLUTANT LOADS

Pollutant loads were determined by multiplying the pollutant event mean concentration (a stream flow volume-weighted mean of analytical results from laboratory analysis) by the total storm discharge at the point of sample collection. Stream discharge volume for a specific time interval (for a specific limb or the total event) is determined by integrating under the flow rate hydrograph over the time period of interest. The pollutant event mean concentration (EMC) for a given storm is determined by:

$$\text{EMC} = \frac{\sum_{i=1}^{3} C_i V_i}{\sum_{i=1}^{3} V_i}$$

Where:

EMC = Event Mean Concentration of specific pollutant

i = Numerical representation of storm limb (1=rising, 2=peak, 3=falling)

C_i = Pollutant concentration at limb i

V_i = Corresponding discharge represented by composite sample collected for limb i.

The average pollutant EMC for the monitoring year is an arithmetic mean of individual storm EMCs.

Pollutant load for a given storm is calculated by:

$$L = (k_1 / k_2) \times (\text{EMC} \times V_T)$$

Where:

L = estimated load in pounds
k_1 = conversion factor 28.317 liters per cubic foot
k_2 = conversion factor of 453,592.4 milligrams per pound
V_T = estimated total storm runoff in stream in ft^3

The average pollutant load for the monitoring year is an arithmetic mean of individual storm loads.

3.6 DETERMINATION OF AVERAGE ANNUAL AND SEASONAL EMC AND TOTAL ANNUAL AND SEASONAL LOAD

Average annual storm EMCs for each pollutant at each station were determined by obtaining the arithmetic mean of individual storm EMC data for a given year. Average annual baseflow Mean Concentrations (MCs) were developed by calculating the arithmetic mean of concentration data. Average seasonal EMCs and MCs were obtained by using the same method, except on a seasonal basis. Below-reportable detection limit results were set to zero when determining average EMCs and determining baseflow MCs.

Total annual load was determined by (a) multiplying all stormflow volume in a given year at a given station by the corresponding average annual EMC for each pollutant, (b) multiplying all baseflow volume in the same year by the corresponding average annual MC, and (c) summing the result.

3.7 SUSPENDED SEDIMENT TRANSPORT MONITORING

Suspended sediment transport was monitored at all three Wheel Creek storm monitoring stations, WC002, WC003, and WC004 (Figure 2-1). Sediment samples were collected in conjunction with wet weather samples from July 2020 through June 2021. Suspended sediment was monitored during eight wet weather sampling events using a modified siphon sampler (Diehl 2008) outfitted with a HOBO® U20 depth logger for continuous stage recording. The modified siphon sampler was developed by USGS to sample shallow water at closely spaced vertical intervals, enabling samples to be collected passively at multiple stages of the rising limb of the hydrograph. Each sampler included six 1000-mL sample containers oriented horizontally with an intake tube and an air vent, which allowed sample collection at up to six two-inch incremental stages. Samples collected were analyzed individually for suspended sediments following a standard method for total suspended solids (SM2540D; APHA 1999), with filtration of the full 1000-mL sample.

Since the sampler devices could not be deployed in the same location as the gauge recorders without causing interference, discharge corresponding to each sample was determined using depth data obtained from the HOBO® loggers. The loggers were set to record pressure and temperature data at 5-minute intervals for the full duration of their deployment. The logger data were then post-processed using HOBOware Pro 2.7.3 software, to correct for changes in barometric pressure. The resulting data were used to determine the approximate time that each sample bottle was filled, and the corresponding discharge from the time of sample collection was obtained from the storm event flow rate graphs for each station. The relationship between discharge and suspended sediment concentration was then plotted to create a sediment-transport curve (Glysson 1987) for each station.

3.8 STATISTICAL TEST FOR TREND

A Kendall's Tau-b statistical test (Kendall 1948) was performed on the compiled baseflow concentration and individual storm EMC data at the monitoring stations. This test is a non-parametric test that compares the ranks of parameter concentrations to the ranked collection dates. The test was used to determine whether a significant upward or downward trend in concentration occurred over time.

3.9 COMPARISON OF PRE- TO POST-RESTORATION DATA

The assessment of the effectiveness of restoration projects in Wheel Creek relies upon comparisons of pre-restoration conditions to post-restoration conditions. Because the implementation of restoration projects in the watershed was staggered, the effectiveness of groups of the projects was determined strategically using the location of the applicable monitoring station and construction timelines. The time periods for the pre-restoration and post-restoration conditions were appropriately defined at each station, so that the during-construction phases were eliminated from the comparisons. Note the following:

- Pre-restoration and post-restoration conditions evaluated using data from Station WC004 were governed only by the construction of Pond C at Festival of Bel Air,
- Pre-restoration phase for data collected at Station WC002 was governed by the earliest construction of projects on the mainstem (i.e., Pond A in September 2012),
- Pre-restoration phase for data collected at Station WC003 was governed by the start of construction at Pond C in May 2015 (same as at Station WC004) but was set to the same timeframe as Station WC002 for consistency, and
- Post-restoration phase at both Station WC002 and Station WC003 was set to the conclusion of construction of Pond E at Country Walk 1B in April 2017 since the effort was upstream of both stations.

The relationship between restoration construction schedule, which monitoring station data are used in efficiency evaluations, and the type of evaluations are provided in Table 3-3.

Comparisons were conducted in two ways: a) total annual load for fiscal years 2017-2021 (post-restoration) to 2010-2011 (pre-restoration); and b) post-restoration storm EMCs and baseflow MCs to pre-restoration storm EMCs and baseflow MCs.

3.9.1 Comparison of Ratios Between Stations WC002 and WC003

Because only one monitoring station is located on the mainstem, the assessment of the effectiveness of restoration projects in improving water quality in the mainstem, as well as projects on the middle branch located between Station WC002 and Station WC003 (e.g., MB-4 and one water quality facility), was isolated and performed indirectly by comparing ratios of pollutant loads and concentrations between the stations during the pre-restoration and post-restoration phases. The ratio (or relationship) of pollutant levels between the two stations during the pre-restoration period was taken as a baseline; a lowering of the ratio during the post-restoration period would indicate pollutant reduction between the stations.

The ratio of total load between the downstream station and the upstream station was calculated for the following pollutants: total nitrogen, total phosphorus, total suspended solids (TSS), ammonia, BOD, copper, lead, and zinc.

For this method, total loads were calculated using data from the pre-restoration period (2010-2011) and post-restoration period (FY 2017-2021) and then compared to one another. The ratio between stations is calculated from the following equation:

$$\text{Ratio} = (1 - (L_3/L_2)) * 100$$

Where:

L_3 = Load at Station WC003 (upstream)
L_2 = Load at Station WC002 (downstream)

To determine restoration effectiveness in terms of storm EMC and baseflow MC, the ratio between the average EMC or MC at the downstream Station WC002 and the upstream Station WC003 was calculated for the pre-restoration time period and the post-restoration time period. The ratios of average concentrations between the downstream station and the upstream station, during both periods, were compared for each analyte. The ratio between stations is calculated from the following equation:

$$\text{Ratio} = (1 - (C_3/C_2)) * 100$$

Where:

C_3 = Concentration at Station WC003 (upstream)
C_2 = Concentration at Station WC002 (downstream)

A paired Student’s t test was used to determine significance of the difference in EMC or MC between the stations.

3.9.2 Comparison of Pre- and Post-Restoration Conditions at all Stations

Calculations of absolute pollutant removal efficiencies were used to characterize the aggregated effectiveness of restoration projects located within each station's subwatershed. Both storm EMC and baseflow MC data accumulated during the pre-restoration and post-restoration phases at each station, defined above, were compared. The efficiencies were calculated using the same percentage equation defined in Section 1.2.1. A Student's t test was used to determine significance.

Table 3-3. Restoration construction schedule, applicable monitoring stations, and recommended efficiency evaluation methods

Construction Projects	Reach	Start Date	Completion Date	No. Storms		No. Baseflows		Efficiency Evaluation
				Pre-restoration	Post-restoration	Pre-restoration	Post-restoration	
Gardens of Bel Air (Pond A)	Mainstem	September 8, 2012	December 20, 2012	17 (WC002) 18 (WC003)	40 (WC002) 39 (WC003)	33 (WC002) 32 (WC003)	62 (WC002) 62 (WC003)	Compare differences between WC002 & WC003 during pre- and post-conditions
Calverts Walk (UMS-1)	Mainstem	January 14, 2013	April 4, 2013					
MMS-5, MB-4	Mainstem, Middle Branch	December 7, 2015	February 26, 2016					
Water Quality Facilities (4)	Mainstem (3), Middle Branch (1)	December 7, 2015	March 18, 2016					
Festival of Bel Air (Pond C)	Middle Branch	May 12, 2015	August 7, 2015	42	49	52	69	WC004 before & after
Country Walk 1A (Pond D)	Middle Branch	September 21, 2015	December 11, 2015	17 (WC002) 18 (WC003)	33 (WC002) 34 (WC003)	33 (WC002) 32 (WC003)	48 (WC002) 48 (WC003)	WC002 before & after; WC003 before & after
MB-1	Middle Branch	December 7, 2015	February 26, 2016					
Country Walk 1B (Pond E)	Middle Branch	December 2016	April 2017					

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4.0 RESULTS AND DISCUSSION

Results of stormflow and baseflow sampling performed from July 1, 2020 through June 30, 2021 are presented and discussed in this section. The individual sample analytical data are compiled into tables while annual average concentrations and loadings are presented in tabular and graphical form.

4.1 STORMFLOW CONCENTRATION RESULTS

Analytical results for storm samples collected at each of the three stations are presented in Table 4-1. Total nitrogen results were greater than the EPA recommended reference value of 0.69 mg/L (U.S. EPA 2000) in 96.8% of the samples in this monitoring period. Of the samples in which total phosphorus was detected, 87.1% of the results were greater than the EPA recommended reference value of 0.03656 mg/L. Orthophosphate was detected in 55.6% of stormflow samples collected. Ammonia results were above the detection limit in 66.7% of stormflow samples collected at all stations during the year. Ammonia concentrations were highest during the February storm event. BOD was detected in 93.7% of samples, with the highest concentrations at all three stations during the February and March storm events.

Zinc was detected in 77.8% of storm samples collected between July 1, 2020 and June 30, 2021. No zinc concentration was greater than MDE's acute criterion for surface water in samples collected during this reporting period (Table 3-2).[1] Zinc concentrations were highest during the February 16, 2021 storm event. Lead concentrations were above the detection limit in 42.9% of the samples, none of which were above the MDE acute criterion. Copper concentrations were above the detection limit in 95.2% of samples; however, only 4.8% were greater than the MDE acute criterion for surface water.

E. coli concentrations were equal to or greater than the maximum reportable result (2,420 MPN/100ml) in 28.6% of stormflow grab samples. *E. coli* concentrations were generally highest at Station WC002 in FY2021, with concentrations of *E. coli* decreasing at Station WC003 and WC004, respectively. TPH was not detected in any of the 21 stormflow grab samples collected at the monitoring stations. Hardness was generally the lowest at Station WC004. Turbidity was generally highest at Station WC003, probably due to the additive effects of suspended matter transported from the stormwater collection pond just upstream of this station. TSS was above the detection limit in 92.1% of samples, with highest concentrations also at Station WC003. Chloride was reported in all of the storm runoff samples, but only one of the reported results exceeded the acute criterion established by USEPA, occurring during the rising limb of the March 19, 2021 storm event. Chloride concentrations were much higher in FY2021 than in FY2020, but less than those seen in FY2018 and FY2019; probably due to the moderate winter and smaller quantities of deicing compound applied on road surfaces in FY2021 compared to other years.

[1] The zinc, lead, and copper criteria are based on the dissolved form, while the laboratory analytical results are for total metal concentration. Comparisons to surface water criteria are for discussion purposes only and do not imply violations of surface water standards.

4.2 BASEFLOW CONCENTRATION RESULTS

Baseflow sample analytical results are presented in Table 4-2. Under baseflow conditions, concentration values for total phosphorus were above the detection limit in 86.1% of samples. Orthophosphate was detected in 36.1% of the baseflow samples. Ammonia was detected in 75.0% of samples, mostly at Station WC002, and TSS was detected in 47.2% of baseflow samples. Total nitrogen was above the detection limit in all the baseflow samples, and all concentration levels were greater than the EPA reference value (0.69 mg/L). Total nitrogen concentrations tended to be lowest at Station WC003 and highest at Station WC004.

Zinc was detected in all baseflow samples and generally at the highest concentrations at Station WC004. Lead and copper were detected in 47.2% and 75.0%, respectively, of baseflow samples. All concentrations of all metals were lower than MDE's applicable chronic surface water criteria.

BOD was detected in 19.4% of samples. Maximum BOD concentrations at all three stations were recorded for August baseflow monitoring event. Baseflow concentrations of nitrate plus nitrite were generally higher at Station WC004 than at the other stations. Turbidity was generally lowest in baseflow samples taken from Station WC004 and highest in baseflow samples taken from Station WC003.

Chloride concentrations were elevated from February through April for all stations. Generally, chloride was highest at Station WC004 for a given baseflow sampling event and became gradually lower when progressing downstream to Station WC002. The maximum observed chloride concentrations for Stations WC003 and WC004 occurred during the March sampling event and for Station WC002 occurred during the February sampling event. The lowest chloride concentrations occurred during the December sampling event at Station WC002, the June sampling event at WC003, and during the August sampling event at Station WC004.

Hardness, a characteristic of surface waters, was quantified in all baseflow samples. Concentrations greater than 120 mg/L are considered "Hard", while concentrations exceeding 180 mg/L are considered "Very Hard". All baseflow samples collected contained "Hard" water, and the highest hardness values were found at Station WC004, where all collected samples were considered "Very Hard".

E. coli bacteria concentrations were detected in all baseflow samples at all stations, ranging in concentration from 6.3 to 1,120 MPN/100ml. The maximum concentrations during the monitoring period for Stations WC002 and WC003 occurred during the September sampling event, and the maximum concentration for Station WC004 occurred during the August sampling event. In general, *E. coli* concentrations were highest during the warmer months and lowest during the colder months.

TPH was only detected in one of the baseflow samples collected from the study area during the monitoring period: the May sample at Station WC003.

Table 4-1. Stormflow water chemistry results, July 2020 – June 2021. All concentrations are in units of mg/L unless indicated.

Storm Date	Limb	Dis-charge (cf)	5-Day BOD	Ammo-nia	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard-ness	Chlor-ide	Turbid-ity (NTU)
Station WC002																		
8/3/2020	Rising	15,349	1.0	0.12	0.90	<0.05	0.4	0.03	<2.0	4	<1.0	<10	<5	2,420.0	1.30	124	91.10	1.80
8/3/2020	Peak	936,481	2.0	<0.30	0.50	0.03	0.5	0.09	8.0	6	<1.0	11	N.C.	N.C.	1.00	20	7.23	9.16
8/3/2020	Falling	18,743	1.0	<0.30	0.60	<0.05	0.5	0.05	3.0	4	<1.0	<10	N.C.	N.C.	1.10	66	33.00	3.43
9/11/2020	Rising	8,184	1.0	0.08	1.10	<0.05	0.4	0.03	<2.0	2	<1.0	<10	N.C.	N.C.	1.50	144	99.90	1.34
9/11/2020	Peak	72,478	4.0	0.08	0.40	0.02	0.8	0.14	33.0	9	1.0	24	N.C.	N.C.	1.20	56	31.60	9.91
9/11/2020	Falling	19,592	2.0	0.06	0.30	<0.05	0.6	0.05	5.0	4	<1.0	<10	<5	1,990.0	0.90	70	42.10	5.67
11/12/2020	Rising	73,508	7.0	0.08	0.50	0.01	0.9	0.08	18.0	6	<2.0	21	N.C.	N.C.	1.40	112	72.00	4.32
11/12/2020	Peak	512,723	4.0	<0.30	0.40	0.05	0.9	0.13	22.0	6	<2.0	<20	<5	>2,420.0	1.30	44	12.90	13.50
11/12/2020	Falling	162,785	2.0	<0.30	0.80	0.02	0.7	0.05	4.0	5	<1.0	16	N.C.	N.C.	1.50	72	38.00	7.56
12/14/2020	Rising	150,428	2.0	0.36	0.40	0.05	0.8	0.16	28.0	7	2.0	23	N.C.	N.C.	1.20	38	20.90	25.70
12/14/2020	Peak	127,728	2.0	0.18	0.30	0.05	0.7	0.14	22.0	7	<2.0	<20	<5	>2,420.0	1.00	38	11.80	25.10
12/14/2020	Falling	41,436	2.0	0.23	0.40	0.04	0.6	0.09	11.0	6	<1.0	14	N.C.	N.C.	1.00	44	25.90	17.10
2/16/2021	Rising	106,892	6.0	0.25	0.70	0.15	1.8	0.33	99.0	16	5.0	93	N.C.	N.C.	2.50	98	566.00	92.80
2/16/2021	Peak	111,197	4.0	0.28	0.50	0.12	1.2	0.21	67.0	9	2.0	64	N.C.	N.C.	1.70	64	378.00	55.60
2/16/2021	Falling	42,713	2.0	0.15	0.50	0.04	0.7	0.09	12.0	5	<1.0	31	<5	613.0	1.20	84	459.00	22.90
3/19/2021	Rising	19,831	2.2	<0.10	1.62	<0.02	<0.5	0.11	6.8	<2	0.2	17	N.C.	N.C.	1.62	146	205.00	4.53
3/19/2021	Peak	64,895	2.9	0.11	0.58	<0.02	0.6	0.10	15.2	5	0.6	28	N.C.	N.C.	1.18	60	206.00	12.80
3/19/2021	Falling	21,428	<2.0	<0.10	0.99	<0.02	<0.5	<0.10	<4.0	1	0.2	19	<5	86.2	0.99	90	209.00	4.90
5/28/2021	Rising	199,122	4.0	0.22	0.90	<0.05	4.2	0.13	5.0	5	<1.0	12	<5	147.0	5.10	128	63.40	2.76
5/28/2021	Peak	166,036	3.0	0.06	0.50	<0.05	0.9	0.07	15.0	9	1.0	24	N.C.	N.C.	1.40	54	66.20	8.66
5/28/2021	Falling	40,893	2.0	<0.30	0.60	<0.05	0.7	0.05	5.0	7	<1.0	11	N.C.	N.C.	1.30	64	60.70	4.64

N.C. = Sample Not Collected

Table 4-1. (Continued)

Storm Date	Limb	Dis-charge (cf)	5-Day BOD	Ammo-nia	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard-ness	Chlor-ide	Turbid-ity (NTU)
Station WC003																		
8/3/2020	Rising	4,187	1.0	<0.30	0.70	<0.05	0.5	0.03	7.0	4	<1.0	12	<5	1,990.0	1.20	142	112.00	3.62
8/3/2020	Peak	591,828	1.0	0.06	0.30	0.02	0.6	0.09	20.0	7	<1.0	12	N.C.	N.C.	0.90	18	7.52	12.20
8/3/2020	Falling	14,115	1.0	0.06	0.30	<0.05	0.4	0.04	10.0	4	<1.0	<10	N.C.	N.C.	0.70	38	22.30	4.69
9/11/2020	Rising	1,255	<1.0	0.13	0.80	<0.05	0.5	0.02	<2.0	2	<1.0	<10	N.C.	N.C.	1.30	140	111.00	1.86
9/11/2020	Peak	43,488	4.0	0.24	0.30	0.03	1.1	0.20	47.0	11	3.0	52	N.C.	N.C.	1.40	52	31.00	19.90
9/11/2020	Falling	9,346	2.0	0.15	0.50	0.01	0.5	0.05	3.0	4	<1.0	<10	<5	1,550.0	1.00	60	38.50	4.17
11/12/2020	Rising	16,002	4.0	0.09	0.60	<0.05	0.8	0.05	19.0	<4	<2.0	<20	N.C.	N.C.	1.40	130	93.80	5.49
11/12/2020	Peak	153,812	3.0	0.07	0.30	0.02	0.8	0.09	19.0	6	<2.0	24	<5	2,420.0	1.10	26	21.50	10.90
11/12/2020	Falling	17,828	2.0	0.10	0.40	0.02	0.6	0.04	4.0	<4	<2.0	<20	N.C.	N.C.	1.00	44	37.50	7.62
12/14/2020	Rising	25,728	2.0	0.12	0.40	0.02	0.8	0.12	34.0	7	1.0	23	N.C.	N.C.	1.20	62	34.80	24.30
12/14/2020	Peak	53,152	2.0	0.08	0.20	0.02	0.6	0.08	15.0	6	<2.0	<20	<5	2,420.0	0.80	36	16.20	20.70
12/14/2020	Falling	35,625	1.0	0.08	0.40	0.06	0.5	0.05	6.0	5	<1.0	14	N.C.	N.C.	0.90	56	35.90	13.00
2/16/2021	Rising	34,566	5.0	0.19	0.60	0.12	1.7	0.31	155.0	16	5.0	101	N.C.	N.C.	2.30	142	778.00	87.40
2/16/2021	Peak	25,623	3.0	0.33	0.40	0.06	1.0	0.16	55.0	8	2.0	55	N.C.	N.C.	1.40	80	547.00	49.60
2/16/2021	Falling	10,329	2.0	0.12	0.40	0.02	0.7	0.08	19.0	7	1.0	35	<5	119.0	1.10	102	622.00	21.70
3/19/2021	Rising	5,525	2.2	<0.10	1.22	<0.02	<0.5	0.13	42.0	3	1.0	33	N.C.	N.C.	1.22	162	291.00	12.80
3/19/2021	Peak	42,857	2.9	<0.10	0.50	<0.02	0.9	0.11	23.6	7	1.0	30	N.C.	N.C.	1.40	87	328.00	17.50
3/19/2021	Falling	9,278	<2.0	<0.10	0.76	<0.02	<0.5	0.10	5.2	1	0.4	21	<5	93.3.0	0.76	96	310.00	6.46
5/28/2021	Rising	66,405	2.0	<0.30	0.80	<0.05	1.0	0.08	17.0	9	1.0	23	<5	201.0	1.80	120	103.00	8.82
5/28/2021	Peak	94,831	3.0	<0.30	0.30	<0.05	0.9	0.04	17.0	8	<1.0	19	N.C.	N.C.	1.20	68	138.00	9.13
5/28/2021	Falling	29,989	1.0	<0.30	0.60	0.01	0.8	0.04	<2.0	6	<1.0	8	N.C.	N.C.	1.40	86	93.90	3.03

N.C. = Sample Not Collected

Table 4-1. (Continued)

Storm Date	Limb	Dis-charge (cf)	5-Day BOD	Ammo-nia	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard-ness	Chlor-ide	Turbid-ity (NTU)
Station WC004																		
8/3/2020	Rising	2,747	2.0	<0.30	0.40	<0.05	0.60	0.04	10.0	7	<1.0	20	<5	249.0	1.00	78	46.70	2.08
8/3/2020	Peak	139,651	1.0	<0.30	0.10	<0.05	0.40	0.03	5.0	3	<1.0	<10	N.C.	N.C.	0.50	16	6.37	3.20
8/3/2020	Falling	5,910	1.0	<0.30	0.20	<0.05	0.60	0.03	3.0	3	<1.0	<10	N.C.	N.C.	0.80	34	18.40	2.21
9/11/2020	Rising	410	3.0	0.11	0.90	0.03	1.10	0.24	61.0	11	3.0	44	N.C.	N.C.	2.00	122	82.30	13.70
9/11/2020	Peak	5,768	3.0	0.07	0.20	0.01	0.80	0.10	27.0	7	<2.0	26	N.C.	N.C.	1.00	26	18.90	11.50
9/11/2020	Falling	4,213	3.0	0.06	0.30	<0.05	0.60	0.05	9.0	9	<2.0	32	N.A.	517.0	0.90	56	40.90	4.31
11/12/2020	Rising	10,822	4.0	0.07	0.30	0.01	0.90	0.07	16.0	10	<1.0	25	N.C.	N.C.	1.20	102	26.60	8.70
11/12/2020	Peak	75,941	2.0	0.06	0.20	<0.05	0.50	0.04	5.0	4	<1.0	12	<5	2,420.0	0.70	28	10.10	4.83
11/12/2020	Falling	23,309	1.0	0.25	0.40	<0.05	0.60	0.03	3.0	4	<1.0	14	N.C.	N.C.	1.00	56	29.80	6.01
12/14/2020	Rising	9,289	2.0	0.11	0.70	0.07	0.80	0.08	22.0	7	1.0	31	N.C.	N.C.	1.50	22	49.30	8.29
12/14/2020	Peak	19,420	1.0	0.08	0.20	0.02	0.60	0.05	8.0	5	<1.0	16	<5	1,990.0	0.80	26	9.57	8.02
12/14/2020	Falling	5,457	<1.0	0.06	0.20	<0.05	0.50	0.03	3.0	5	<1.0	28	N.C.	N.C.	0.70	32	23.40	4.98
2/16/2021	Rising	5,380	4.0	0.20	0.70	0.04	1.30	0.18	83.0	14	4.0	116	N.C.	N.C.	2.00	124	796.00	31.30
2/16/2021	Peak	18,733	3.0	0.19	0.30	0.04	0.70	0.11	23.0	7	2.0	54	N.C.	N.C.	1.00	56	733.00	26.60
2/16/2021	Falling	4,874	2.0	0.14	0.40	0.01	0.50	0.05	16.0	4	<1.0	40	<5	41.4	0.90	60	655.00	15.30
3/19/2021	Rising	2,375	3.6	<0.10	1.62	<0.02	0.90	0.10	32.8	1	1.0	57	N.C.	N.C.	2.52	189	972.00	11.70
3/19/2021	Peak	18,047	3.4	0.14	0.31	0.02	0.92	0.16	20.0	4	1.0	44	N.C.	N.C.	1.23	54	370.00	16.80
3/19/2021	Falling	2,997	2.3	0.11	0.64	0.07	<0.50	0.11	6.5	3	0.6	35	<5	488.0	0.64	76	367.00	10.20
5/28/2021	Rising	29,208	3.0	<0.30	1.50	0.01	1.10	0.09	30.0	10	1.0	37	<5	649.0	2.60	196	130.00	11.00
5/28/2021	Peak	61,460	3.0	<0.30	0.30	<0.05	1.00	0.06	19.0	9	1.0	30	N.C.	N.C.	1.30	40	149.00	6.28
5/28/2021	Falling	5,500	1.0	<0.30	0.40	0.01	0.90	0.04	4.0	8	1.0	25	N.C.	N.C.	1.30	50	105.00	3.14

N.C. = Sample Not Collected
N.A. = Sample broken at water testing lab by courier; not analyzed

Table 4-2. Baseflow water chemistry results, July 2020 – June 2021. All concentrations are in units of mg/L unless indicated.

Baseflow Date	5-Day BOD	Ammo-nia	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard-ness	Chlor-ide	Turbid-ity (NTU)
Station WC002																
7/9/2020	<1	0.24	1.3	<0.07	0.3	0.03	5	<2.0	0.06	8	<5	194.0	1.6	162	120	1.80
8/27/2020	3	0.26	1.2	<0.05	0.4	0.02	7	0.8	0.20	9	<5	219.0	1.6	152	105	1.17
9/29/2020	<1	0.14	1.3	0.03	1.4	0.12	18	1.0	0.10	12	<5	488.0	1.7	150	103	2.64
10/28/2020	<1	0.16	1.3	<0.07	0.3	0.02	3	1.0	0.30	14	<5	102.0	1.6	168	116	0.62
11/25/2020	<1	0.09	1.6	<0.05	0.4	0.02	8	1.0	0.30	14	<5	34.5	2.0	168	115	3.41
12/8/2020	<1	0.32	1.7	<0.05	0.3	0.02	<2	<2.0	<1.00	6	<5	77.1	2.0	140	100	1.78
1/7/2021	2	0.15	1.8	0.01	0.3	0.02	<2	0.8	0.10	11	<5	25.6	2.1	156	138	0.96
2/9/2021	1	0.43	1.8	<0.05	0.6	0.02	2	0.5	<1.00	20	<5	88.6	2.4	151	297	4.27
3/15/2021	1	0.20	1.8	0.06	0.5	0.13	6	1.0	0.07	14	<5	35.9	2.3	168	250	0.93
4/5/2021	<1	0.08	1.5	0.01	0.5	0.02	3	0.3	<1.00	8	<5	25.6	2.0	151	152	1.21
5/12/2021	<1	0.15	1.5	<0.05	0.5	0.02	6	1.0	0.20	12	<5	39.9	2.0	150	127	1.56
6/7/2021	<1	0.20	1.4	<0.05	0.6	0.03	<2	8.0	<1.00	6	<5	285.0	2.0	146	103	1.84
Station WC003																
7/9/2020	<1	<0.30	0.9	<0.07	0.4	0.02	13	<2.0	<1.00	6	<5	114.0	1.3	174	139	4.49
8/27/2020	2	0.11	1.0	<0.05	0.5	0.03	8	1.0	0.30	11	<5	206.0	1.5	146	121	2.44
9/29/2020	<1	0.06	1.0	0.03	0.5	0.02	<1	0.7	<1.00	8	<5	435.0	1.5	160	116	1.65
10/28/2020	<1	0.09	0.9	<0.07	0.4	0.02	3	0.5	0.07	11	<5	178.0	1.3	240	135	2.08
11/25/2020	<1	0.09	1.2	<0.05	0.4	0.02	<2	0.3	<1.00	12	<5	28.8	1.6	180	133	1.63
12/8/2020	<1	0.10	1.1	<0.05	0.4	0.02	<2	<2.0	<1.00	5	<5	85.7	1.5	140	106	2.73
1/7/2021	<1	<0.30	1.3	0.01	0.3	0.02	<2	0.8	0.20	12	<5	12.1	1.6	168	156	1.28
2/9/2021	<1	0.15	1.2	0.01	0.4	<0.05	<2	<2.0	<1.00	16	<5	6.3	1.6	152	306	1.77
3/15/2021	<1	0.09	1.3	<0.05	0.5	<0.05	<2	0.6	<1.00	12	<5	42.2	1.8	188	317	0.92
4/5/2021	<1	0.08	1.1	0.03	0.5	<0.05	<2	0.5	<1.00	9	<5	23.8	1.6	158	204	1.08
5/12/2021	<1	0.13	1.3	0.04	0.5	0.03	3	<2.0	0.06	9	5.7	30.9	1.8	154	148	1.83
6/7/2021	<1	0.12	1.2	<0.05	0.7	0.02	<2	<1.0	<1.00	6	<5	98.5	1.9	140	105	1.50

Table 4-2. (Continued)

Baseflow Date	5-Day BOD	Ammo-nia	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard-ness	Chlor-ide	Turbid-ity (NTU)
Station WC004																
7/9/2020	1	<0.30	2.3	<0.07	0.4	0.02	5	1.0	0.20	17	<5	816.0	2.7	220	187	3.36
8/27/2020	2	<0.30	2.1	<0.05	0.4	<0.05	<2	2.0	0.10	14	<5	1,120.0	2.5	226	184	0.29
9/29/2020	<1	0.07	2.5	0.02	0.4	<0.05	<1	0.8	<1.00	18	<5	228.0	2.9	246	197	0.42
10/28/2020	<1	0.05	2.4	<0.07	0.4	0.01	<2	0.8	<1.00	18	<5	387.0	2.8	266	223	0.36
11/25/2020	<1	<0.30	2.7	<0.05	0.2	0.04	<2	0.4	<1.00	19	<5	118.0	2.9	254	226	0.31
12/8/2020	<1	0.05	2.5	<0.05	0.3	0.02	<2	<2.0	<1.00	10	<5	40.8	2.8	210	195	1.12
1/7/2021	<1	<0.30	2.7	0.01	0.2	0.01	<2	0.8	<1.00	19	<5	12.2	2.9	228	272	0.41
2/9/2021	<1	0.06	2.3	0.01	0.3	0.02	<2	0.6	<1.00	24	<5	12.0	2.6	202	403	1.49
3/15/2021	<1	<0.30	2.6	0.03	0.5	0.06	3	2.0	0.20	30	<5	25.3	3.1	284	997	1.03
4/5/2021	<1	<0.30	2.5	<0.05	0.4	0.01	<2	1.0	0.20	29	<5	12.1	2.9	256	421	0.43
5/12/2021	<1	<0.30	3.0	<0.05	0.5	0.02	3	<2.0	0.08	18	<5	88.0	3.5	274	320	0.29
6/7/2021	<1	0.11	2.5	<0.05	0.6	0.02	4	1.0	<1.00	16	<5	326.0	3.1	266	272	0.96

4.3 BASEFLOW MEAN AND STORM EVENT MEAN CONCENTRATION DATA

EMC values for each parameter were calculated at each station for each storm event (Table 4-3). Average annual baseflow concentration and storm EMC values were calculated for each pollutant at each station (Table 4-4). Average concentration data computed for storm and baseflows over the course of a year were used to characterize pollutant concentrations during average baseflow conditions or an average stormflow event (Figures 4-1 through 4-6). Total annual and seasonal baseflow mean concentrations, storm EMCs, and loads for each pollutant are presented in Appendix D and Appendix E, respectively.

Under baseflow conditions, average concentrations of combined nitrate plus nitrite, chloride, zinc, and *E. coli* were highest at Station WC004 compared to the other two stations downstream (Figures 4-1 through 4-6). Concentrations of ammonia were disproportionally highest at Station WC002, 222.2% higher than the next highest mean concentration. The higher concentrations of *E. coli* and combined nitrate plus nitrite at Station WC004 may indicate a continued nutrient and septic input in the vicinity of the station. The excessive levels of ammonia at Station WC002 may indicate the presence of a chronic problem such as leakage from a sanitary sewage line. Higher average chloride values may be the result of mobilization of chloride in groundwater as a result of runoff from legacy deicing compound application at the Festival of Bel Air Shopping Center and along Route 24. Samples collected at Station WC003 had the highest average concentrations of TPH during baseflow conditions, while Station WC002 samples had the highest average concentrations of BOD, TKN, ammonia, total phosphorus, lead, copper, and TSS at baseflow conditions. Average baseflow concentrations of orthophosphate were the same at all three stations.

Under stormflow conditions, average EMCs were highest at Station WC004 for chloride (Figures 4-1 through 4-6), which was most likely the result of washing of accumulated deicing compounds in runoff from paved parking areas at Festival of Bel Air and the roadbed of Route 24. Average EMCs for BOD, ammonia, nitrate plus nitrite, TKN, orthophosphate, and *E. coli* were highest at Station WC002. At Station WC003, TSS, copper, lead, and zinc were highest of the three stations. Stations WC002 and WC003 shared the highest average EMCs for total phosphorus. TPH was not recorded in any of the stormflow samples. All average stormflow EMCs exceeded corresponding baseflow mean concentrations at all stations except combined nitrate plus nitrite (all three stations), chloride (Stations WC002 and WC004), ammonia (Station WC002 only) and TPH (Station WC003 only). Average EMCs of all pollutants at all stations were lower than Maryland and national average values (Table 4-4).

Time-series plots of the annual average pollutant concentrations measured from 2010 to FY2021 are shown in Figure 4-7 through Figure 4-15, illustrating the change, on an annual basis, in pollutant concentrations as restoration projects were implemented in the watershed. Plots of average annual storm EMCs and baseflow MCs (with individual non-detect concentrations set to zero) are presented for the following pollutants: nitrate-nitrite, TKN, total phosphorus, TSS, copper, zinc, lead, ammonia, and BOD. Note that data from the shortened reporting period comprising the first six months of calendar year 2015 were not included in the plots.

Table 4-3. Storm event mean concentration results (mg/L except where indicated), July 2020 – June 2021 (non-detects set to zero).

Storm Date	Rainfall (inches)	5-Day BOD	Ammonia	Nitrate + Nitrite	Orthophos-phate	TKN	Total P	TSS	Chloride	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)
Station WC002												
8/3/2020	3.89	1.96	0.00	0.51	0.03	0.50	0.09	7.78	9.05	5.93	0.00	10.61
9/11/2020	0.34	3.36	0.08	0.44	0.01	0.73	0.11	24.83	39.23	7.45	0.72	17.35
11/12/2020	2.15	3.86	0.01	0.50	0.04	0.86	0.11	17.70	24.16	5.78	0.00	5.54
12/14/2020	0.98	2.00	0.27	0.36	0.05	0.73	0.14	23.40	17.91	6.87	0.94	12.64
2/16/2021	0.81	4.49	0.25	0.58	0.12	1.36	0.24	71.11	468.32	11.21	2.90	70.48
3/19/2021	0.73	2.18	0.07	0.86	0.00	0.37	0.08	10.56	206.42	3.26	0.44	24.13
5/28/2021	1.58	3.39	0.13	0.71	0.00	2.50	0.10	9.09	64.27	6.84	0.41	16.81
Station WC003												
8/3/2020	3.89	1.00	0.06	0.30	0.02	0.59	0.09	19.68	8.58	6.91	0.00	11.72
9/11/2020	0.34	3.56	0.22	0.35	0.03	0.98	0.17	38.31	34.15	9.58	2.41	41.81
11/12/2020	2.15	2.99	0.07	0.34	0.02	0.78	0.08	17.57	29.19	4.92	0.00	19.67
12/14/2020	0.98	1.69	0.09	0.31	0.03	0.61	0.08	16.47	26.51	5.91	0.22	9.52
2/16/2021	0.81	3.83	0.23	0.50	0.08	1.30	0.22	98.74	671.22	11.77	3.32	74.62
3/19/2021	0.73	2.37	0.00	0.61	0.00	0.67	0.11	22.40	321.56	5.65	0.90	28.84
5/28/2021	1.58	2.34	0.00	0.52	0.00	0.92	0.05	14.33	118.93	8.03	0.35	18.66
Station WC004												
8/3/2020	3.89	1.02	0.00	0.11	0.00	0.41	0.03	5.01	7.60	3.07	0.00	0.37
9/11/2020	0.34	3.00	0.07	0.27	0.01	0.73	0.09	21.04	30.32	7.97	0.12	29.14
11/12/2020	2.15	1.98	0.10	0.25	0.00	0.56	0.04	5.66	15.89	4.59	0.00	13.70
12/14/2020	0.98	1.11	0.08	0.34	0.03	0.64	0.05	11.01	22.58	5.54	0.27	21.99
2/16/2021	0.81	3.02	0.18	0.39	0.03	0.78	0.11	32.96	731.58	7.79	2.03	63.15
3/19/2021	0.73	3.28	0.12	0.49	0.02	0.80	0.15	19.57	430.67	3.57	0.95	44.17
5/28/2021	1.58	2.89	0.00	0.67	0.00	1.02	0.07	21.48	140.71	9.25	1.00	31.84

Table 4-4. Average storm EMCs and baseflow mean concentrations, Wheel Creek Watershed, July 2020 – June 2021 (non-detects set to zero). All concentrations are in units of mg/L unless indicated.

Station	5-Day BOD	Ammonia	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Chlor-ide	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)
Storm Event Mean Concentrations													
WC002	3.04	0.11	0.56	0.04	1.01	0.12	23.49	118.48	6.76	0.77	22.51	0.00	1,442.31
WC003	2.54	0.10	0.42	0.03	0.84	0.12	32.50	172.88	7.54	1.03	29.26	0.00	1,256.19
WC004	2.33	0.08	0.36	0.01	0.71	0.08	16.68	197.05	5.97	0.62	29.20	0.00	907.77
MD avg[a]	14.44	N.R.	0.85	N.R.	1.94	0.33	66.57	N.R.	17.9	12.5	143.3	N.R.	N.R.
NSQD[b]	16.943	N.R.	1.587	N.R.	2.921	0.412	111.295	N.R.	42	41	250	2.759	N.R.
NURP[c]	9	N.R.	0.68	N.R.	1.5	0.33	100	N.R.	34	144	160	N.R.	N.R.
Baseflow Mean Concentrations													
WC002	0.58	0.20	1.52	0.01	0.51	0.04	4.83	143.83	1.28	0.11	11.17	0.00	134.60
WC003	0.17	0.09	1.13	0.01	0.46	0.02	2.25	165.50	0.37	0.05	9.75	0.48	105.11
WC004	0.25	0.03	2.51	0.01	0.38	0.02	1.25	324.75	0.87	0.07	19.33	0.00	265.45

N.R. = Reference data not available.
[a] = Maryland State average values from Bahr 1997.
[b] = National Stormwater Quality Database values for Maryland from Pitt 2008.
[c] = National Urban Runoff Program values from U.S. EPA 1983.

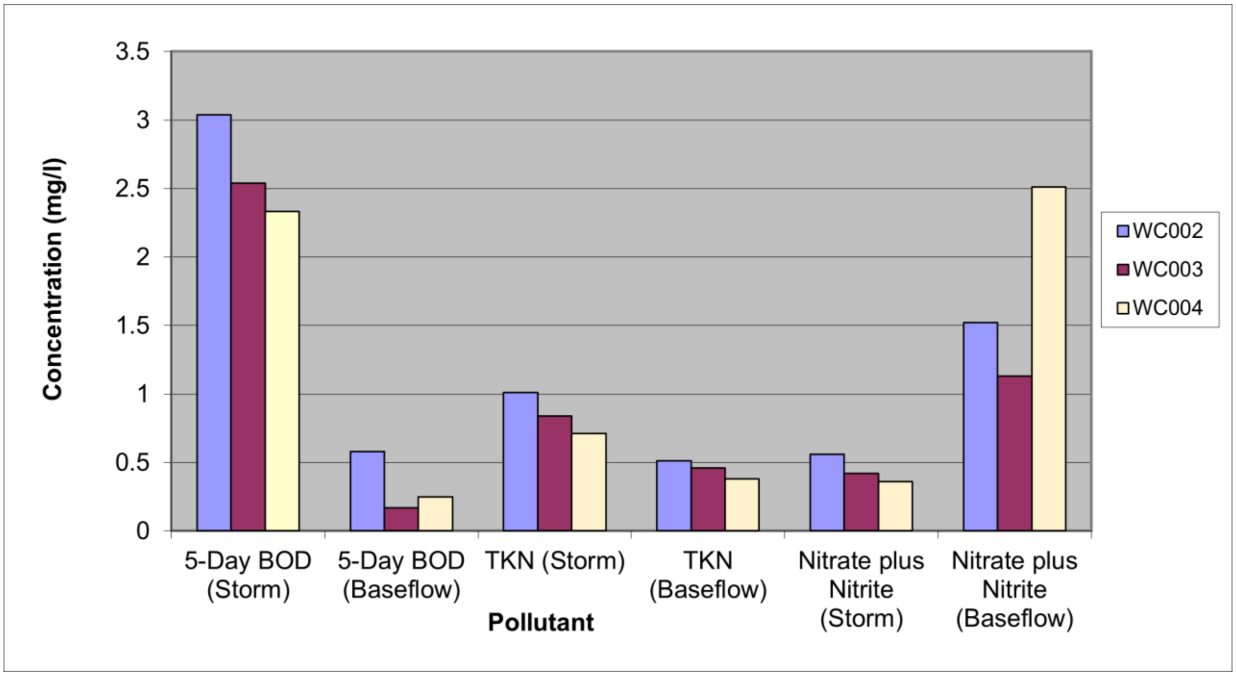

Figure 4-1. Nitrogen and 5-day BOD average storm event mean and baseflow mean concentrations in Wheel Creek, July 2020 – June 2021

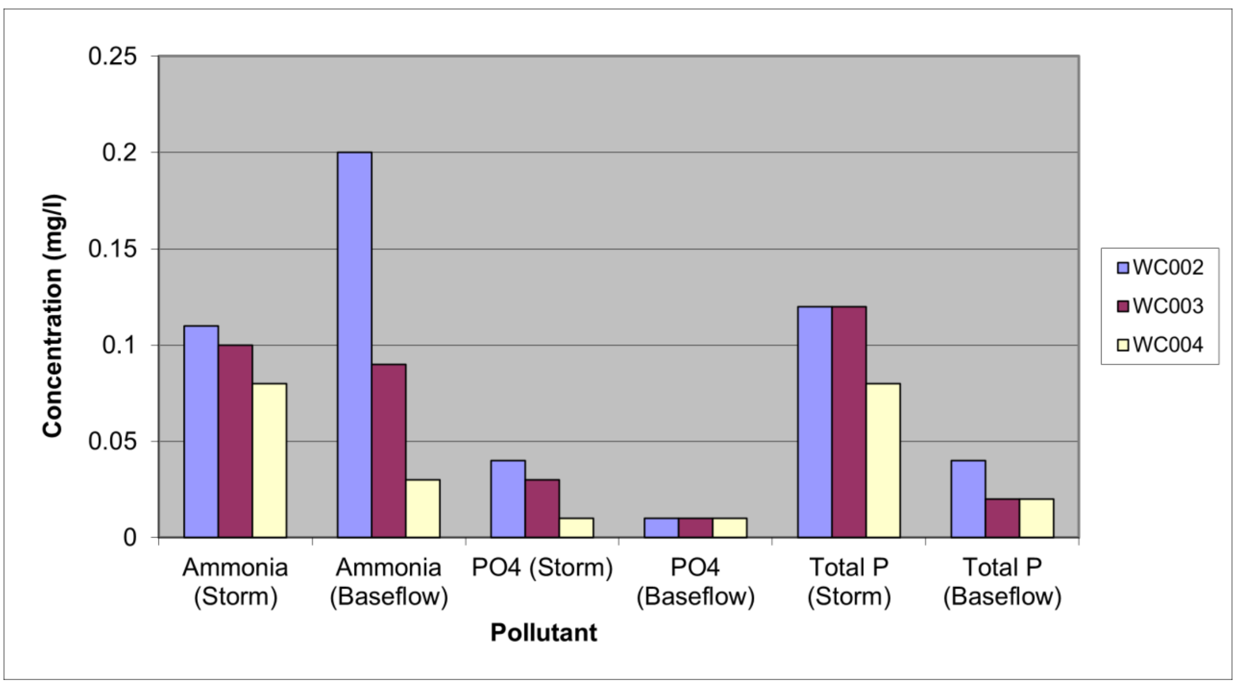

Figure 4-2. Ammonia and phosphorus average storm event mean and baseflow mean concentrations in Wheel Creek, July 2020 – June 2021

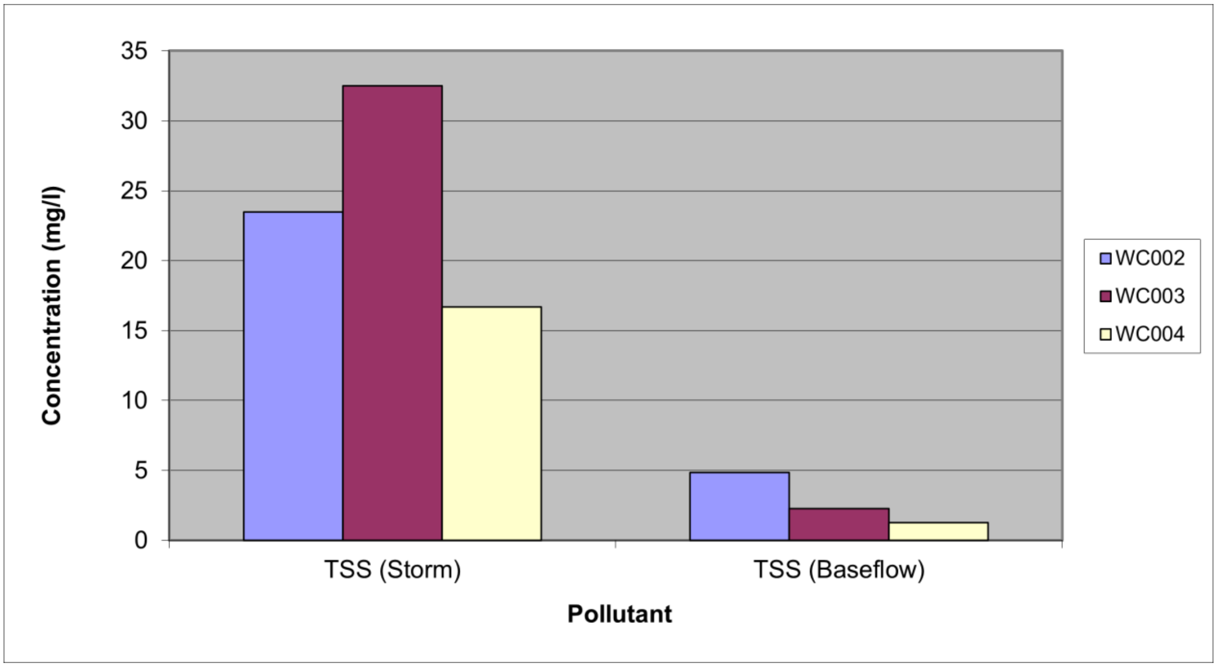

Figure 4-3. TSS average storm event and baseflow mean concentrations in Wheel Creek, July 2020 – June 2021

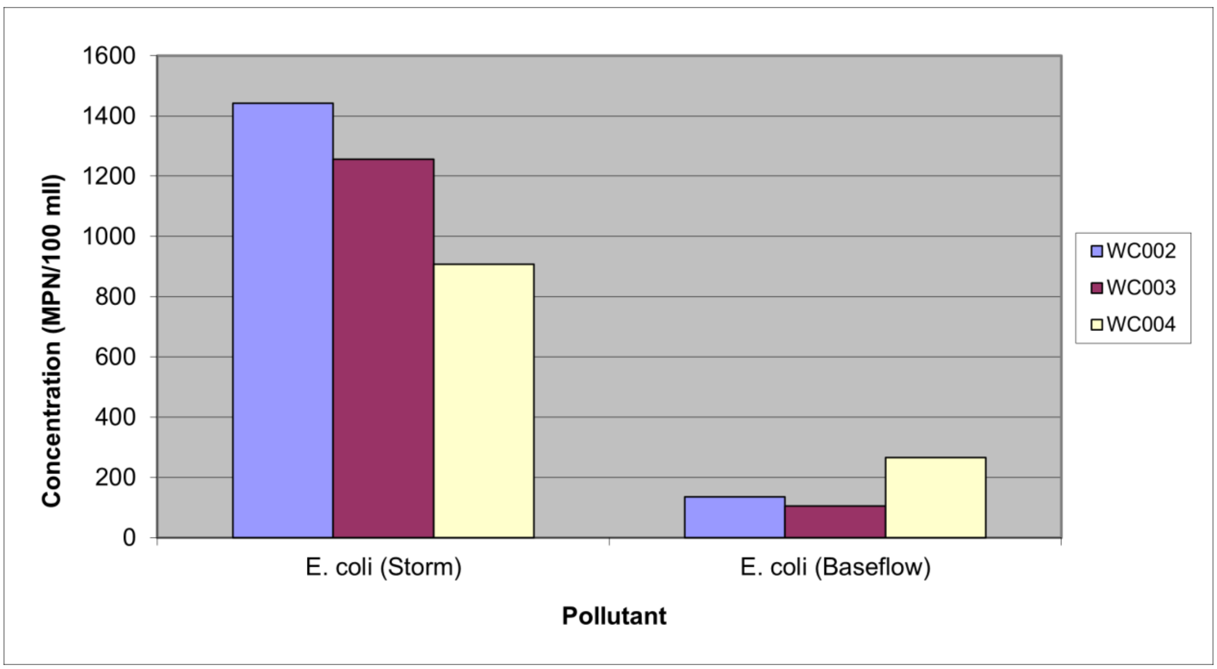

Figure 4-4. *E. coli* average storm and baseflow mean concentrations in Wheel Creek, July 2020 – June 2021

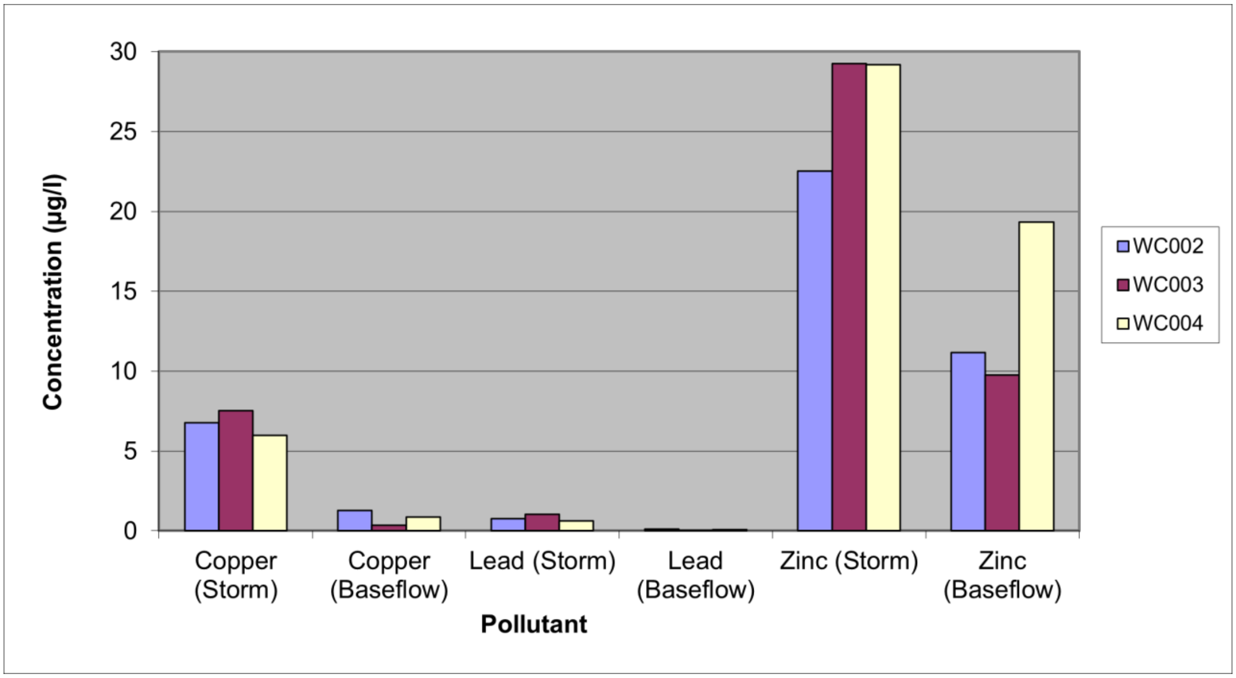

Figure 4-5. Metal average storm event mean and baseflow mean concentrations in Wheel Creek, July 2020 – June 2021

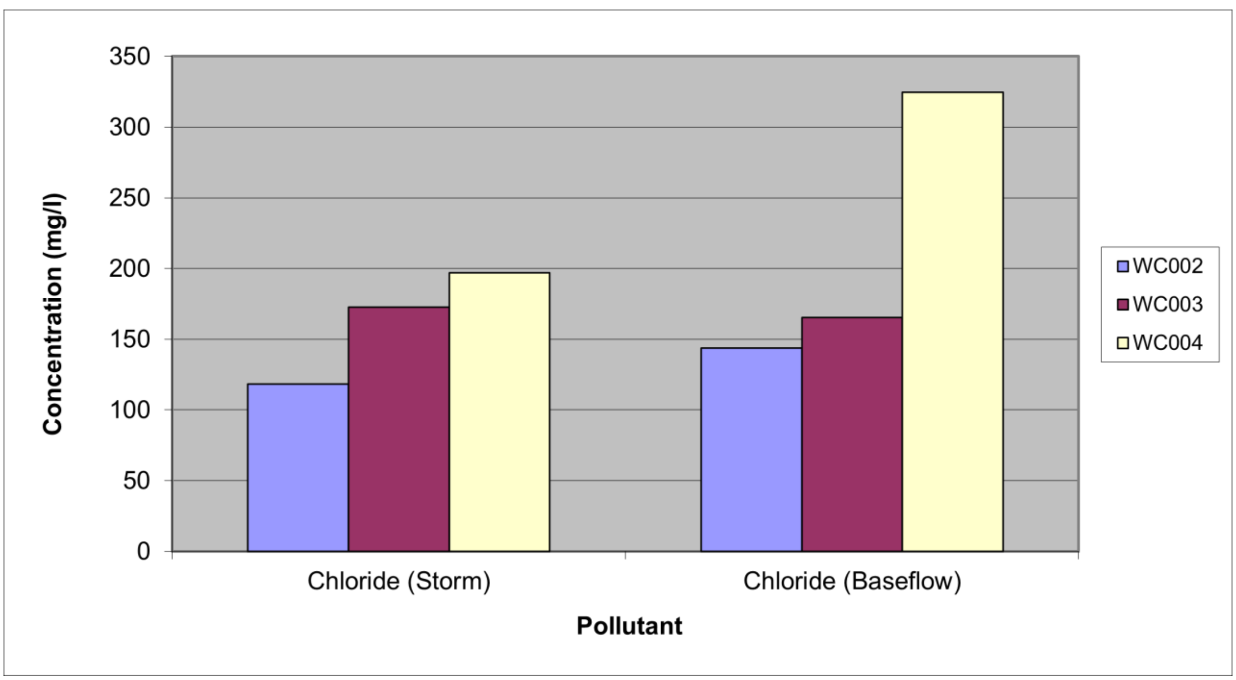

Figure 4-6. Chloride storm event mean and baseflow mean concentrations in Wheel Creek, July 2020 – June 2021

Visually, some of the plots show a potential change in long-term trend in annual concentration data that can be associated with completion of restoration projects in the watershed. For nitrate plus nitrite, while FY2021 showed a slight increase in baseflow MC at Station WC003, the prevailing trend continues gradually downward at all stations since approximately 2014, coinciding with the completion of most of the restoration projects. Storm EMCs for several of the parameters, such as total phosphorus, TSS, copper, and BOD show signs of gradually increasing trend until approximately FY2017 and then notably falling in FY2018 through FY2020. All four of these constituents showed signs of an increasing trend again in FY2021. Average storm EMCs for TKN behaved similarly in FY2018 but rebounded in FY2019 through FY2021 at all stations. Conversely, EMCs for ammonia gradually decreased through FY2017, from which point there has been variability in average storm EMCs and baseflow MCs but still an increasing trend through FY2021. Lead EMCs for two out of three stations declined in FY2019 and FY2020 but increased for two of the three stations in FY2021; zinc EMCs declined at all three stations in FY2020 compared to the previous year and continued this trend in FY2021 except for Station WC003 which showed a slight increase in average storm EMC. The time series data may indicate that the restoration efforts, in concert, are having the desired effect of reducing parameters under specific flow regimes except for ammonia, total phosphorus, and TKN. Continued monitoring is recommended to distinguish a permanent change in long-term pollutant concentrations.

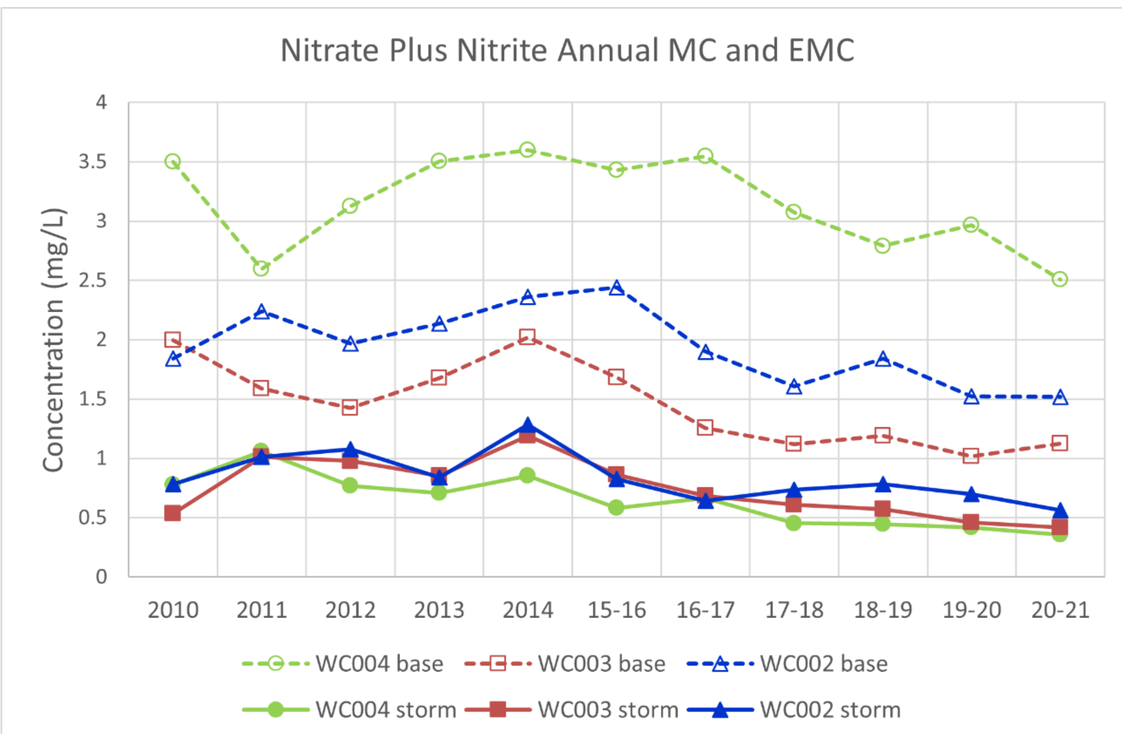

Figure 4-7. Time series plot of average annual baseflow MC and stormflow EMC for nitrate-nitrite (2010-FY2021)

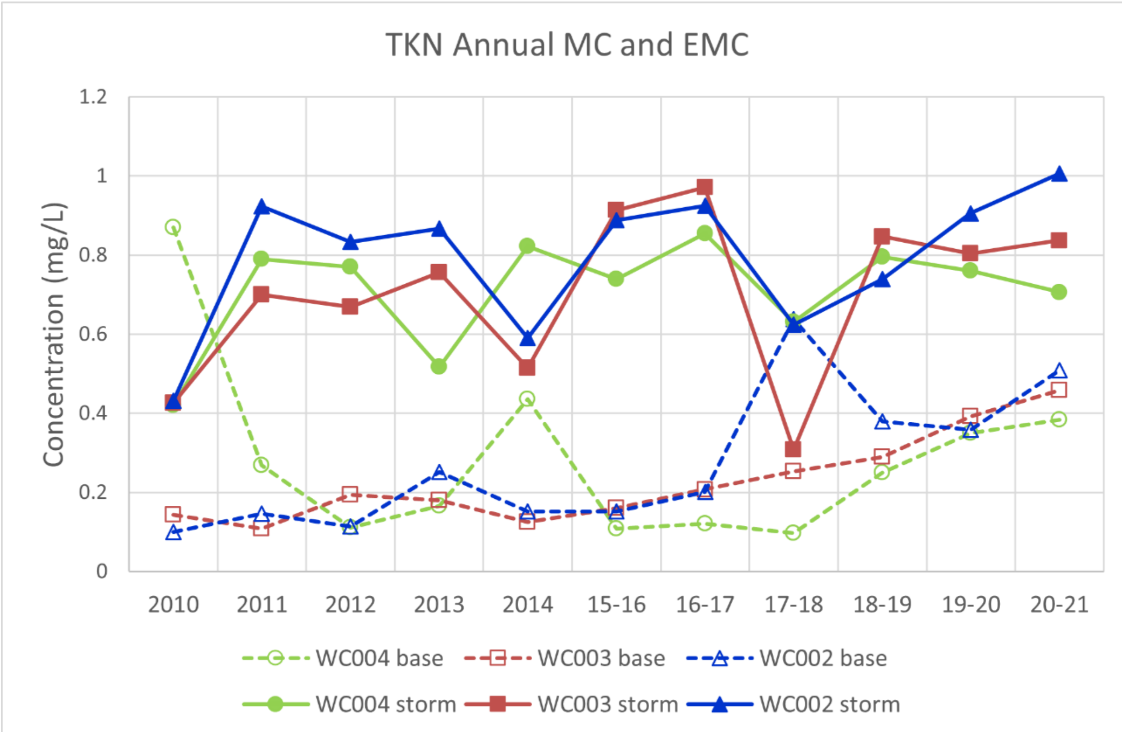

Figure 4-8. Time series plot of average annual baseflow MC and stormflow EMC for TKN (2010-FY2021)

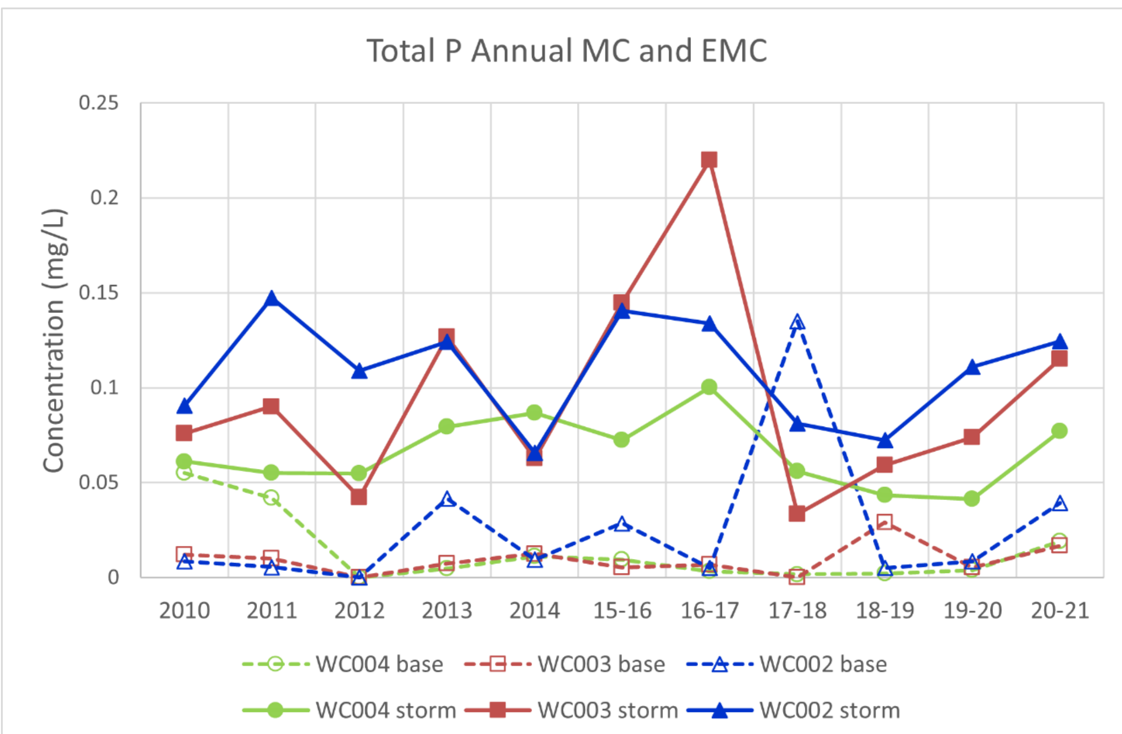

Figure 4-9. Time series plot of average annual baseflow MC and stormflow EMC for total phosphorus (2010-FY2021)

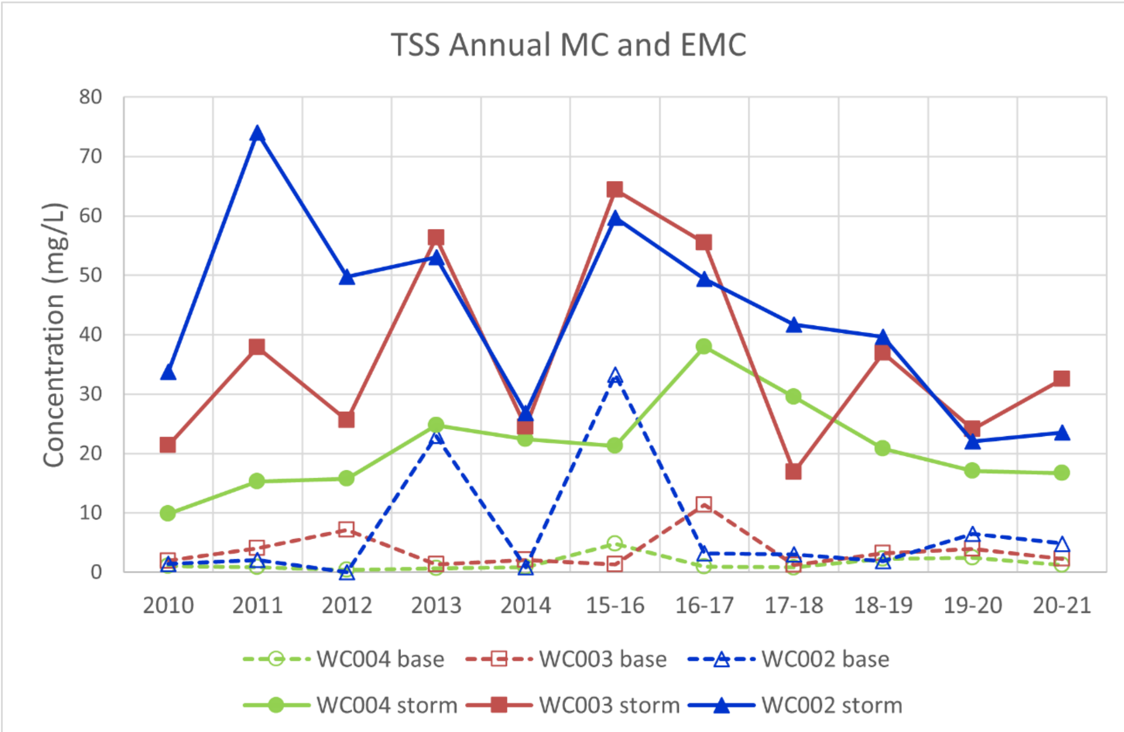

Figure 4-10. Time series plot of average annual baseflow MC and stormflow EMC for TSS (2010-FY2021)

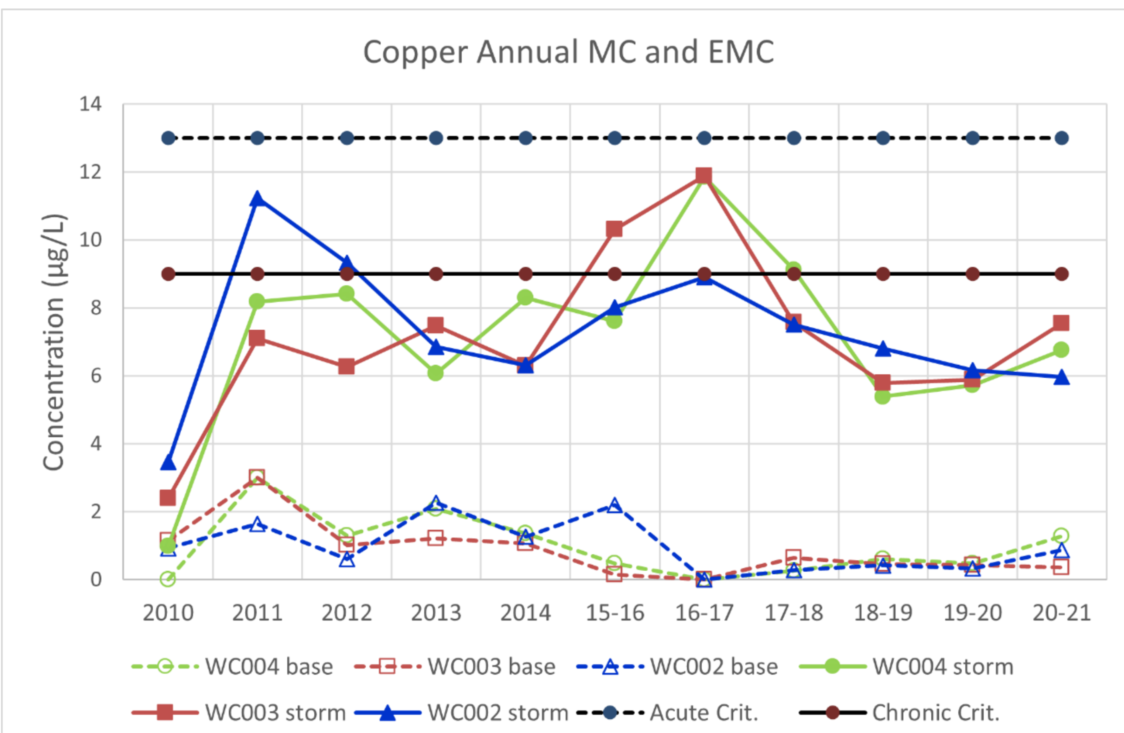

Figure 4-11. Time series plot of average annual baseflow MC and stormflow EMC for copper (2010-FY2021)

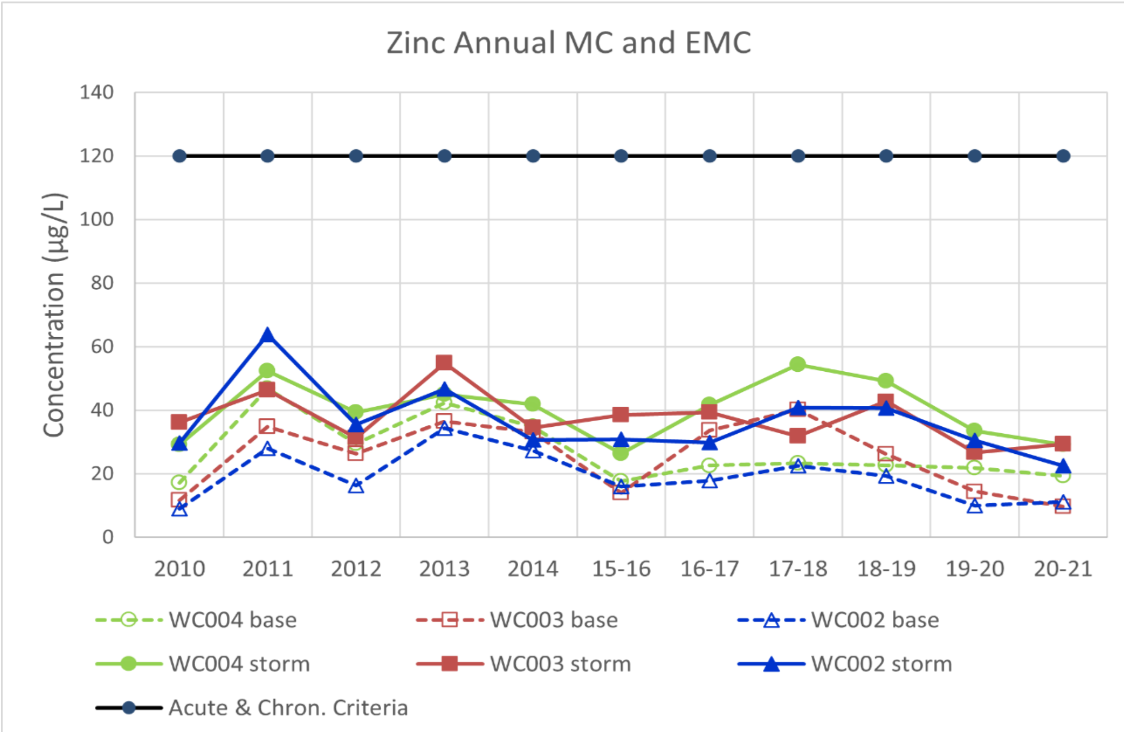

Figure 4-12. Time series plot of average annual baseflow MC and stormflow EMC for zinc (2010-FY2021)

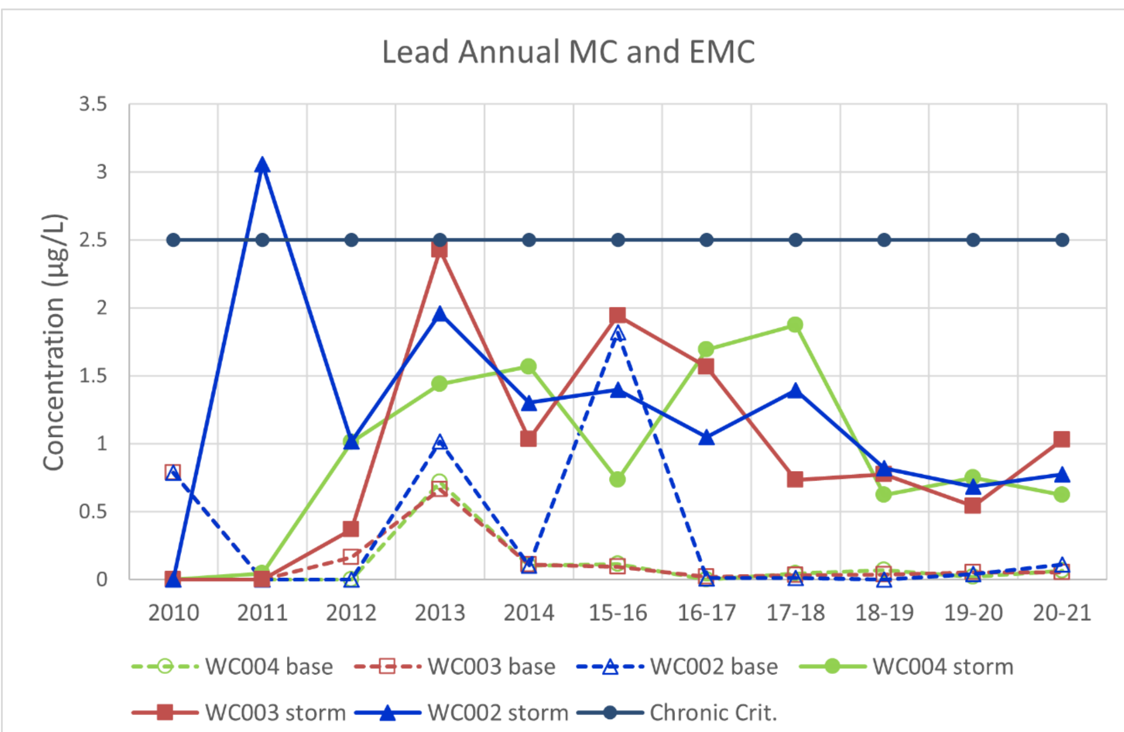

Figure 4-13. Time series plot of average annual baseflow MC and stormflow EMC for lead (2010-FY2021). Note: the acute criterion is not shown to maintain small scale.

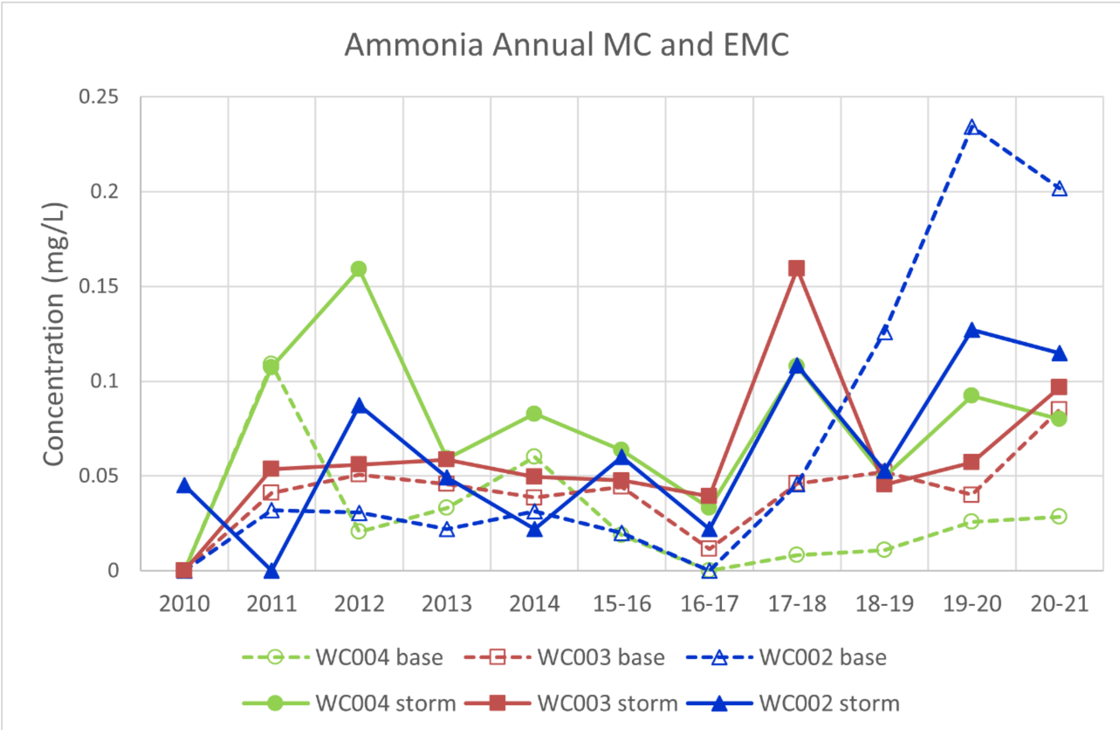

Figure 4-14. Time series plot of average annual baseflow MC and stormflow MC for ammonia (2010-FY2021)

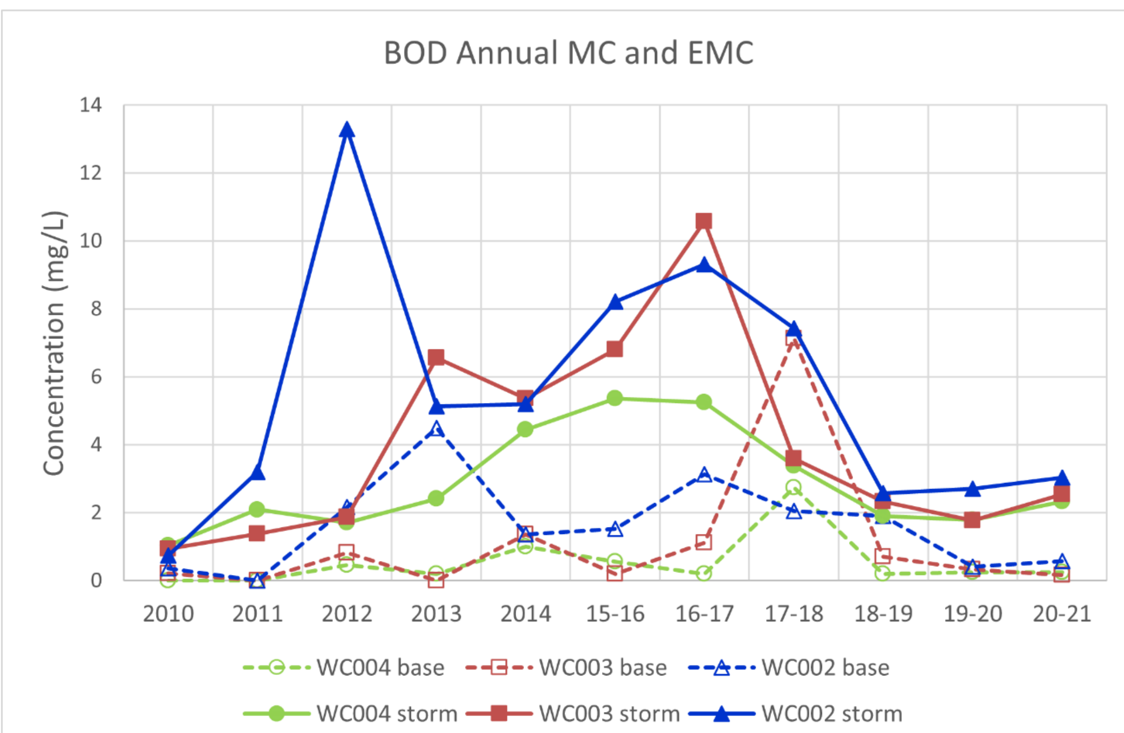

Figure 4-15. Time series plot of average annual baseflow MC and stormflow MC for BOD (2010-FY2021)

4.4 STORMFLOW POLLUTANT LOADING DATA

Pollutant loads for individual storms at each station were calculated from individual stormflow event mean concentration data (Table 4-5). Pollutant load represents the quantity of pollutant, in pounds, that was transported in the stream during the event. For discussion purposes, an average load was determined for each pollutant at each station for storms monitored from July 2020 through June 2021. Since the final wet weather event of FY2021 initiated on June 30, 2021 but continued until July 2, 2021, average load results in this report exclude this result. Results from this storm will be included in the Year 12 report.

When comparing stations, average storm loads were highest at Station WC002 for all parameters (Table 4-6). Average loads were lowest at Station WC004 for all parameters. Since discharge volume for a given storm increases with distance downstream, maximum load results at Station WC002 are expected.

4.5 SEDIMENT TRANSPORT SAMPLING RESULTS

A summary of suspended sediment transport data for Stations WC002, WC003, and WC004 and suspended sediment transport curves for Stations WC002 and WC003 are presented below. The discharges associated with each sediment sample were approximated from flow rate data recorded at the time when the stage at which the samplers filled, as shown by stage loggers attached to the siphon samplers, was achieved.

Of the eight sampling events from July 2020 to June 2021, siphon samplers were deployed for seven storms. Suspended sediment samples were not collected from the first sampling event of FY2021 due to ongoing contract negotiations with the testing laboratory. Additionally, due to the overlap between fiscal years and the final sampling event on June 30, 2021, suspended sediment concentrations from this event will be reported in the Year 12 report. From the six storms with concentration data from FY2021, a total of 25 samples were collected at Station WC002 (Table 4-7), 20 samples were collected at Station WC003 (Table 4-8), and 21 samples were collected at Station WC004 (Table 4-9). Note that bottles are numbered in sequence from the lowest to the highest point in the water column. Suspended sediment concentrations ranged from 1.6 to 470.0 mg/L at Station WC002, 13.8 to 1,300.0 mg/L at Station WC003, and 0.0 to 1,350.0 mg/L at Station WC004.

Table 4-5. Storm event pollutant loadings (lbs per event), July 2020 – June 2021 (non-detects set to zero).

Storm Date	Discharge (cf)	5-Day BOD	Ammonia	Nitrate + Nitrite	Ortho-phosphate	TKN	Total P	TSS	Chloride	Copper	Lead	Zinc
Station WC002												
8/3/2020	2,938,020	360.39	0.35	93.22	5.31	91.42	16.19	1,426.40	1,660.64	1.088	0.000	1.947
9/11/2020	78,848	16.56	0.37	2.15	0.07	3.58	0.56	122.24	193.09	0.037	0.004	0.085
11/12/2020	1,723,900	415.39	0.84	53.46	4.26	92.18	11.59	1,904.38	2,599.56	0.622	0.000	0.596
12/14/2020	455,980	56.93	7.72	10.25	1.39	20.90	4.07	666.04	509.86	0.196	0.027	0.360
2/16/2021	547,737	153.61	8.43	19.90	4.08	46.64	8.19	2,431.47	16,013.76	0.383	0.099	2.410
3/19/2021	281,573	38.39	1.18	15.07	0.00	6.45	1.44	185.67	3,628.43	0.057	0.008	0.424
5/28/2021	692,439	146.53	5.72	30.53	0.00	107.99	4.21	392.90	2,778.37	0.296	0.018	0.726
Station WC003												
8/3/2020	1,350,840	84.33	5.03	25.53	1.64	50.15	7.46	1,659.57	723.46	0.583	0.000	0.989
9/11/2020	78,849	17.53	1.09	1.70	0.13	4.84	0.84	188.56	168.11	0.047	0.012	0.206
11/12/2020	594,567	110.99	2.77	12.44	0.68	28.99	3.04	652.34	1,083.31	0.183	0.000	0.730
12/14/2020	2,237,649	235.92	12.43	42.91	4.53	85.75	11.13	2,300.58	3,703.00	0.826	0.031	1.330
2/16/2021	146,857	35.15	2.11	4.57	0.77	11.91	2.03	905.29	6,153.69	0.108	0.030	0.684
3/19/2021	143,084	21.14	0.00	5.46	0.00	5.98	0.99	200.11	2,872.30	0.050	0.008	0.258
5/28/2021	354,579	51.78	0.00	11.53	0.03	20.34	1.19	317.29	2,632.59	0.178	0.008	0.413
Station WC004												
8/3/2020	617,860	39.29	0.00	4.23	0.00	15.88	1.16	193.36	293.01	0.119	0.000	0.014
9/11/2020	34,981	6.55	0.15	0.59	0.01	1.60	0.19	45.95	66.21	0.017	0.000	0.064
11/12/2020	265,501	32.90	1.68	4.18	0.02	9.29	0.68	93.78	263.44	0.076	0.000	0.227
12/14/2020	632,805	43.94	3.36	13.27	1.20	25.22	2.17	434.86	892.04	0.219	0.011	0.869
2/16/2021	71,785	13.52	0.82	1.75	0.16	3.49	0.51	147.70	3,278.49	0.035	0.009	0.283
3/19/2021	56,257	11.52	0.43	1.70	0.09	2.81	0.52	68.73	1,512.51	0.013	0.003	0.155
5/28/2021	167,659	30.20	0.00	7.01	0.04	10.72	0.71	224.85	1,472.79	0.097	0.010	0.333

Table 4-6. Average storm pollutant loads (lbs/event), Wheel Creek monitoring, July 2020 – June 2021 (non-detects set to zero)

Station	5-Day BOD	Ammonia	Nitrate + Nitrite	Ortho-phosphate	TKN	Total P	TSS	Chloride	Copper	Lead	Zinc
WC002	169.68	3.52	32.08	2.16	52.74	6.61	1,018.44	3,911.96	0.38	0.02	0.94
WC003	79.55	3.35	14.88	1.11	29.71	3.81	889.11	2,476.64	0.28	0.01	0.66
WC004	25.42	0.92	4.68	0.22	9.86	0.85	172.75	1,111.21	0.08	0.00	0.28

Table 4-7. Suspended sediment results at Station WC002, July 2020 – June 2021							
Date	**Bottle Number**	**Suspended Sediment (mg/L)**	**Discharge (cfs)**	**Date**	**Bottle Number**	**Suspended Sediment (mg/L)**	**Discharge (cfs)**
11-Sep-20	1	25.8	0.97	16-Feb-21	1	4.4	0.95
11-Sep-20	2	58.7	0.88	16-Feb-21	2	326.0	1.08
11-Sep-20	3	233.0	2.82	16-Feb-21	3	123.0	1.41
12-Nov-20	1	4.6	1.80	16-Feb-21	4	290.0	4.27
12-Nov-20	2	8.5	1.80	16-Feb-21	5	243.0	11.00
12-Nov-20	3	16.7	1.80	19-Mar-21	1	112.0	1.04
12-Nov-20	4	24.5	4.94	19-Mar-21	2	7.1	1.52
12-Nov-20	5	59.2	14.66	1-Jun-21	1	156.0	0.81
12-Nov-20	6	73.7	29.22	1-Jun-21	2	25.1	0.95
13-Dec-20	1	1.6	0.80	1-Jun-21	3	355.0	1.37
13-Dec-20	2	33.1	0.89	1-Jun-21	4	470.0	19.31
13-Dec-20	3	35.8	2.65	1-Jun-21	5	409.0	40.82
13-Dec-20	4	42.2	7.49				

Table 4-8. Suspended sediment results at Station WC003, July 2020 – June 2021							
Date	**Bottle Number**	**Suspended Sediment (mg/L)**	**Discharge (cfs)**	**Date**	**Bottle Number**	**Suspended Sediment (mg/L)**	**Discharge (cfs)**
11-Sep-20	1	146.0	1.65	13-Dec-20	3	50.7	7.04
11-Sep-20	2	502.0	5.43	16-Feb-21	1	25.8	0.21
11-Sep-20	3	335.0	9.52	16-Feb-21	2	123.0	3.52
11-Sep-20	3	137.0	N.R.	16-Feb-21	3	301.0	6.86
12-Nov-20	1	1050.0	0.25	16-Feb-21	4	237.0	N.R.
12-Nov-20	2	174.0	0.48	19-Mar-21	1	18.7	0.19
12-Nov-20	3	23.6	2.52	1-Jun-21	1	99.0	3.16
12-Nov-20	4	28.3	6.96	1-Jun-21	2	1300.0	9.82
13-Dec-20	1	72.3	1.14	1-Jun-21	3	644.0	10.43
13-Dec-20	2	48.7	4.32	1-Jun-21	4	402	N.R.
N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.							

Date	Bottle Number	Suspended Sediment (mg/L)	Discharge	Date	Bottle Number	Suspended Sediment (mg/L)	Discharge
11-Sep-20	1	346.0	1.62	16-Feb-21	2	125.0	1.76
11-Sep-20	2	73.3	2.60	16-Feb-21	3	135.0	4.82
11-Sep-20	3	195.0	N.R.	16-Feb-21	4	52.0	N.R.
11-Sep-20	4	88.5	N.R.	16-Feb-21	5	115.0	N.R.
12-Nov-20	1	19.7	0.67	19-Mar-21	1	43.6	0.18
12-Nov-20	2	12.7	9.14	19-Mar-21	2	0.0	N.R.
13-Dec-20	1	35.2	0.14	1-Jun-21	1	1350.0	0.24
13-Dec-20	2	143.0	1.09	1-Jun-21	2	N.S.	5.27
13-Dec-20	3	18.6	2.86	1-Jun-21	3	64.8	N.R.
13-Dec-20	4	16.0	N.R.	1-Jun-21	4	110.0	N.R.
16-Feb-21	1	86.2	0.17	1-Jun-21	5	52.1	N.R.

Table 4-9. Suspended sediment results at Station WC004, July 2020 – June 2021

N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.
N.S. – Corresponding sample failed to collect in siphon sampler at this stage.

Sediment transport curves were created for each station using concentrations of suspended sediment in samples and corresponding flow rate values for storms monitored from July 2020 through June 2021. Average instantaneous discharges for each sample were approximately the same as those reported in the previous year. Results at Station WC002 showed a low correlation between discharge and suspended sediment concentration ($r^2 = 0.21$; Figure 4-16). The sediment transport curve prepared for Station WC003 showed a low correlation between discharge and suspended sediment concentration ($r^2 = 0.23$; Figure 4-17). The sediment concentration correlation at Station WC003 was similar to that reported last year, but with higher concentrations per discharge noted. Results at Station WC004 showed almost no correlation between discharge and suspended sediment concentration ($r^2 = 0.08$; Figure 4-18); higher suspended sediment concentrations per discharge were also recorded at Station WC004 in FY2021.

The arithmetic mean of stormflow-associated suspended sediment concentrations, by station, exceeded corresponding average annual EMCs of TSS, suggesting that TSS results underestimate the actual transport of sediment during storms (Figure 4-19).

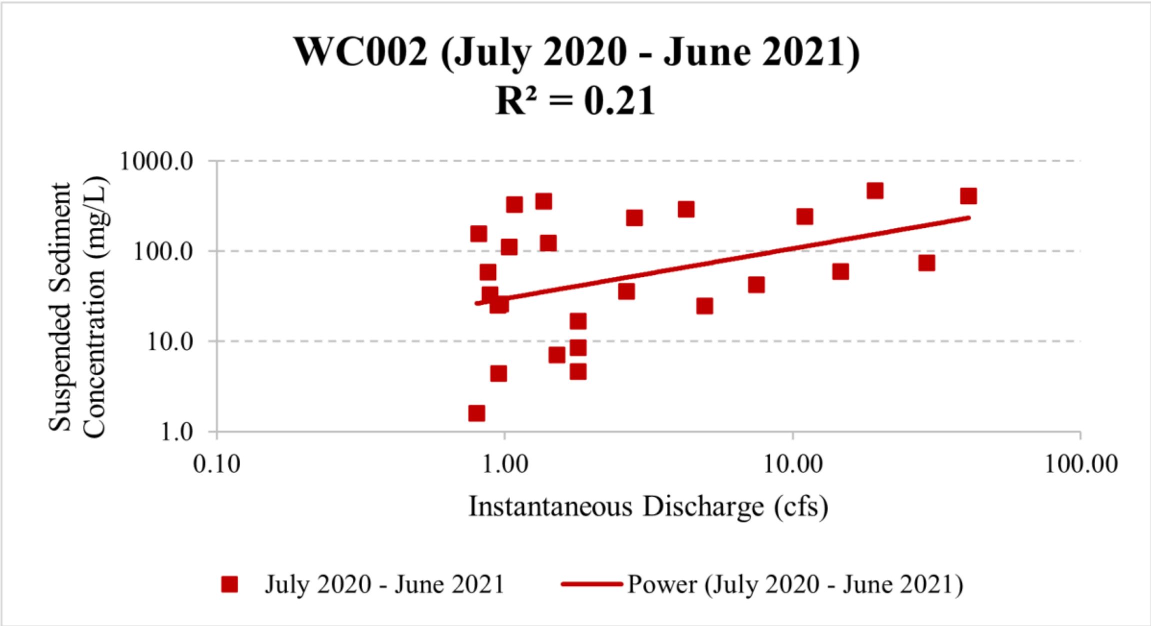

Figure 4-16. Suspended sediment curve for Wheel Creek Station 002 (July 2020 – June 2021)

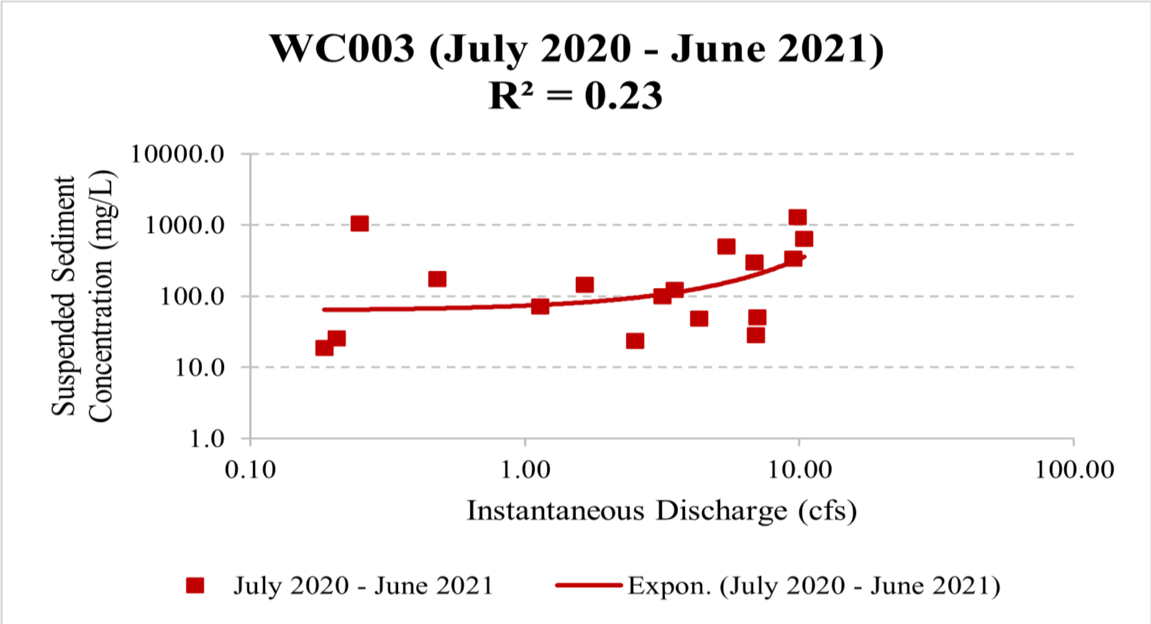

Figure 4-17. Suspended sediment curve for Wheel Creek Station 003 (July 2020 – June 2021)

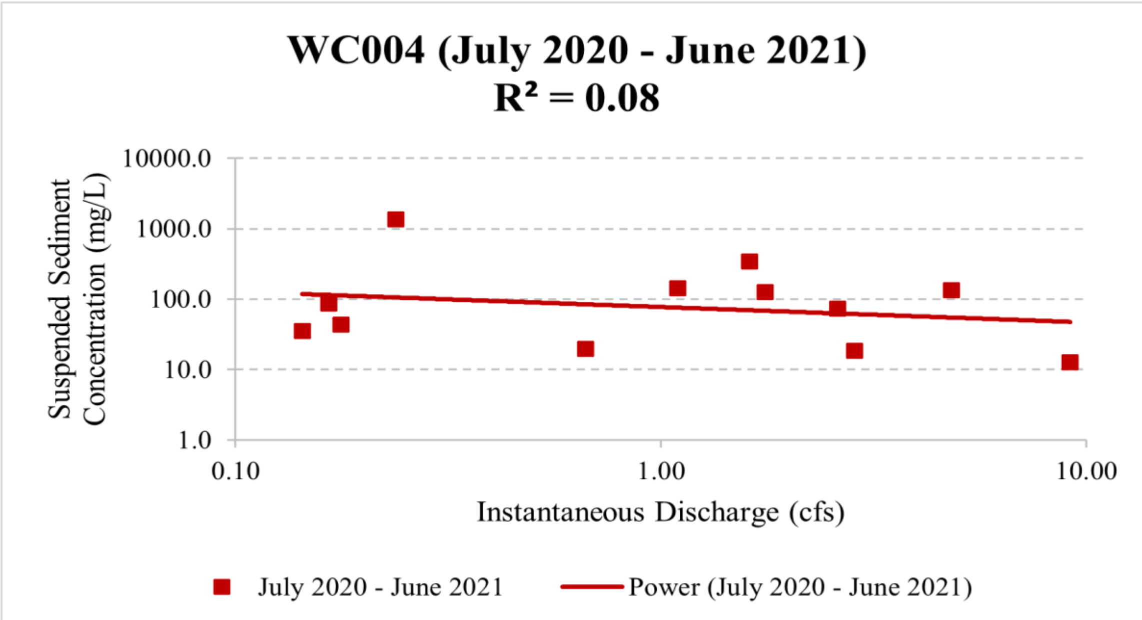

Figure 4-18. Suspended sediment curve for Wheel Creek Station 003 (July 2020 – June 2021)

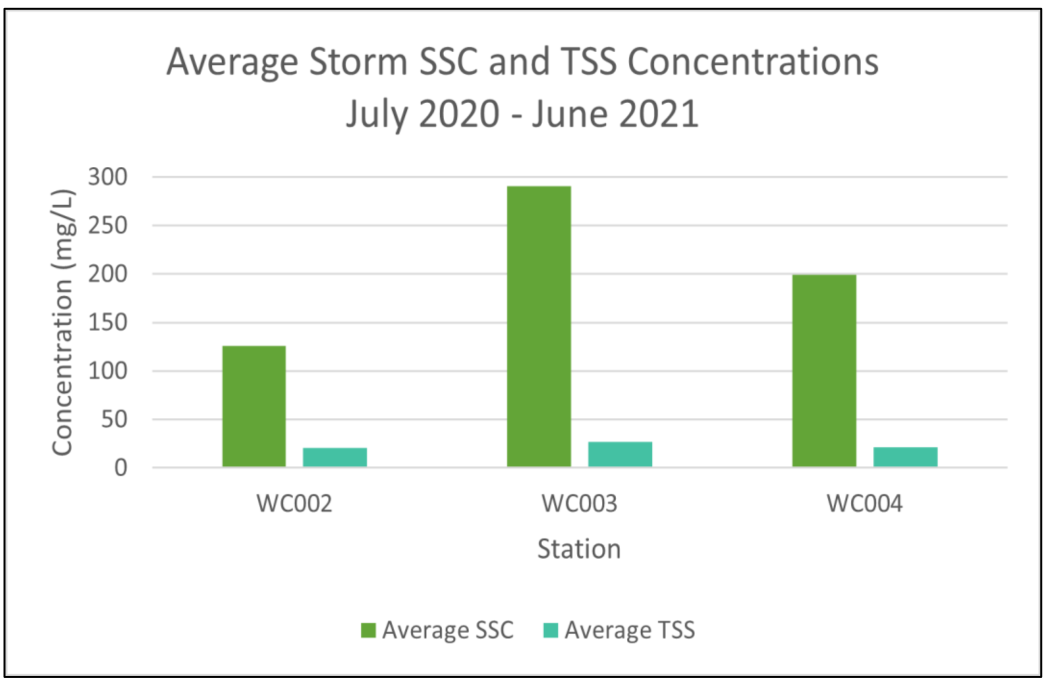

Figure 4-19. Average SSC and TSS concentrations in stormwater runoff (July 2020 – June 2021)

4.6 MONITORING PROBLEMS IDENTIFIED IN 2020-2021

4.6.1 Storm Events

During the August 3-5, 2020 storm event, the bubbler line detached from the sensor at Stations WC002 and WC003 due to debris transported through the culverts. To approximate proportional aliquots for compositing, field staff used the flow data and hydrograph from Station WC004.

During the November 11-12, 2020 storm event, the bubbler line detached from the sensor at Stations WC002 and WC003 due to debris transported through the culverts. To approximate proportional aliquots for compositing, field staff used the flow data and hydrograph from Station WC004. Flush samples were collected during the composite visit due to the setup for the storm falling on a holiday.

During the February 15-16, 2021 storm event, the bubbler line detached from the sensor at Station WC002 due to debris transported through the culverts. To approximate proportional aliquots for compositing, field staff used the flow data and hydrograph from Station WC003.

During the March 18-19, 2021 storm event, the bubbler line detached from the sensor carrier at Station WC002 station during the storm event due to debris transported through the culvert. Station WC003 station also had debris transported through the culvert that caused the both the sensor carrier and tubing to be completely detached from the pipe. To approximate proportional aliquots for compositing, field staff used the flow data and hydrograph from Station WC004.

4.6.2 Continuous Stage Logging

The Solinst level loggers at each station were downloaded monthly. Episodes of sensor drift due to presence of sediment after storm flows and leaf debris in the fall have been noted. The level loggers occasionally accumulate sediment in the sensor holes, which needs to be removed. Leaf debris buildup in the channels causes a temporary backwater condition, causing heightened stage and artificially inflated flow rate readings. Adjustments to correct for the drift and leaf buildup were performed to improve the flow record.

In the winter, there were several months when the Solinst level loggers were removed from the stream due to cold weather and risk of damage to sensors from ice buildup. To reduce data gaps, ISCO bubbler flowmeters were installed at each site when the Solinst instruments were temporarily removed. Bubbler flowmeters are less prone to damage due to ice buildup around the sensor.

To account for data gaps, the following protocols were used to complete the stage records. All data from the Solinst level loggers were aggregated, and anomalous data encountered during data offloads and logger swapping were manually interpolated with the surrounding stage data. The level logger data were shifted to match observed actual staff gauge readings, and linear drift corrections were applied to correct periods of sensor drift. ISCO flowmeter data were also shifted to match staff gauge observations and Solinst level logger data; the ISCO level data were used when Solinst level loggers were offline. When needed, barometric pressure data from a nearby weather station were used for pressure compensations of the instream Solinst level loggers. If equipment failures occurred, stream level data were modelled using a regression to determine the relationship between stations to estimate flow rate and fill in any resultant data gaps.

4.7 COMPARISON OF PRE- AND POST-RESTORATION CONDITIONS

4.7.1 Comparison of Pollutant Ratios Between Stations WC002 and WC003

For this evaluation, a comparison of the ratios (in percent; see definition in section 3.9.1) of average pollutant concentrations and annual loads between Station WC003 and Station WC002 was employed to determine the benefit, in terms of pollution reduction, of restoration projects in the mainstem and in the middle branch between Station WC003 and Station WC002.

Total Annual Load

For the purpose of comparison, samples collected in 2010 and 2011 were treated as fully "pre-restoration" and those collected in FY2017-2021 were treated as fully "post-restoration." If the ratio of pollutant load between the upstream station (WC003) and downstream station (WC002) during post-restoration conditions was less than the baseline ratio during pre-restoration conditions, then it may be concluded that the restoration projects reduced loading between the stations. Total loads and ratios are presented in Table 4-10. For comparison, intermediate post-restoration results using data collected in 2014, when no construction was in progress in the study area, are provided as in Jones et al. (2016).

In terms of total annual load, the ratios of the downstream station (WC002) to the upstream station (WC003) for nutrients were equal or greater during post-restoration conditions than during pre-restoration conditions. Lead, copper, zinc, BOD, and TSS ratios were lower during the post-restoration phase, indicating that the restoration between the stations succeeded in reducing pollutant loads for these pollutants.

Storm EMCs

The ratios of average EMCs of pollutants during storm events captured during pre-restoration conditions were compared to the ratios of average EMCs for storms captured during post-restoration conditions. The average EMCs during these periods, and comparisons between periods, are provided in Table 4-11.

For all pollutants except ammonia, the average storm EMCs at the downstream station exceeded those at the upstream during pre-restoration; however, none of the differences were significant. After completion of restoration projects, only the average storm EMC of copper was less than at the upstream. Total nitrogen, TSS, BOD, and lead at the downstream station, conversely, were substantially higher than at the upstream station, though only the difference for total nitrogen was significant. The change in ratios suggests that the restoration in the contributing subwatersheds has reduced pollutant concentrations at Station WC002 under stormflow conditions for all parameters except for total nitrogen and ammonia.

Table 4-10. Comparison of Pre-Restoration and Post-Restoration Total Annual Loads

Phase	Total Load (lbs)		Ratio
	WC002	WC003	
Total Nitrogen			
Pre-Restoration (2010-2011)	7,258	1,905	73.8%
Post-Restoration (2014)	6,958	1,307	81.2%
Post-Restoration (FY 2017-21)	24,140	5,634	76.7%
Total Phosphorus			
Pre-Restoration (2010-2011)	281.8	73.9	73.8%
Post-Restoration (2014)	171.5	33.4	80.5%
Post-Restoration (FY 2017-21)	1,088.0	285.1	73.8%
TSS			
Pre-Restoration (2010-2011)	126,203	26,438	79.1%
Post-Restoration (2014)	67,237	12,413	81.5%
Post-Restoration (FY 2017-21)	276,433	99,523	64.0%
Ammonia			
Pre-Restoration (2010-2011)	72.4	32.1	55.7%
Post-Restoration (2014)	83.3	32.7	60.7%
Post-Restoration (FY 2017-21)	1,431.0	306.9	78.6%
BOD			
Pre-Restoration (2010-2011)	4,914	1,030	79.0%
Post-Restoration (2014)	14,168	2,918	79.4%
Post-Restoration (FY 2017-21)	42,486	12,258	71.1%
Copper			
Pre-Restoration (2010-2011)	19.2	4.9	74.3%
Post-Restoration (2014)	16.8	3.3	80.3%
Post-Restoration (FY 2017-21)	55.5	22.1	60.1%
Lead			
Pre-Restoration (2010-2011)	4.4	0.2	96.3%
Post-Restoration (2014)	3.3	0.5	84.1%
Post-Restoration (FY 2017-21)	8.6	3.4	60.3%
Zinc			
Pre-Restoration (2010-2011)	137.9	43.7	68.3%
Post-Restoration (2014)	101.1	24.2	76.1%
Post-Restoration (FY 2017-21)	360.9	131.7	63.5%

Table 4-11. Pre- and Post-Restoration Average Storm EMCs (shaded cells indicate significant results)

Pollutant (mg/L)	Station WC002	Station WC003	Ratio	t test p-value (two-tailed)
Pre-Restoration Conditions				
Total N	1.50	1.44	4%	0.60
Total P	0.104	0.073	30%	0.17
TSS	46.84	28.54	39%	0.13
Ammonia	0.017	0.030	-72%	0.48
BOD	2.400	1.585	34%	0.12
Copper	0.008	0.006	27%	0.17
Lead	0.479	0.000	100%	0.33
Zinc	0.043	0.038	11%	0.56
Post-Restoration Conditions				
Total N	1.57	1.26	20%	0.02
Total P	0.107	0.094	12%	0.54
TSS	37.65	32.06	15%	0.46
Ammonia	0.089	0.083	8%	0.76
BOD	5.326	3.981	25%	0.24
Copper	0.007	0.008	-5%	0.75
Lead	0.0011	0.0009	17%	0.54
Zinc	0.033	0.033	-1%	0.93
Note: For all pollutants, $\alpha = 0.05$				

Baseflow MCs

The ratios of average baseflow MCs of pollutants during pre-restoration conditions were compared to the ratios of average baseflow MCs during post-restoration conditions. The average MCs during these periods, and comparisons between periods, are provided in Table 4-12.

During pre-restoration phase baseflow conditions, total phosphorus, TSS, ammonia, copper, and zinc concentrations at the upstream station exceeded those at the downstream station, with TSS and zinc significant. Concentrations of BOD and total nitrogen were higher at the downstream station. After restoration, only BOD and zinc showed improvement in terms of lowering ratios between the upstream and downstream stations, with zinc showing a significant decrease. For the remaining parameters, concentrations at the downstream station became greater in relation to the upstream station, with total nitrogen and ammonia showing significant increases. The significantly higher ammonia concentrations at Station WC002 may be due to contributions of ammonia from a potential sanitary sewage source. However, average annual *E. coli* MCs were lowest at Station WC002. *E. coli* EMCs were highest at Station WC002, which better correlated to ammonia concentrations.

Table 4-12. Pre- and Post-Restoration Average Baseflow MCs (shaded cells indicate significant results)

Pollutant (mg/L)	Station		Ratio	t test p-value (two-tailed)
	WC002	WC003		
Pre-Restoration Conditions				
Total N	2.14	1.88	12%	0.22
Total P	0.006	0.040	-617%	0.28
TSS	1.38	3.36	-144%	0.04
Ammonia	0.016	0.030	-86%	0.19
BOD	0.900	0.387	57%	0.25
Copper	0.001	0.002	-55%	0.23
Lead	0.0003	0.0003	0%	N/A
Zinc	0.017	0.021	-25%	0.01
Post-Restoration Conditions				
Total N	2.07	1.46	30%	<0.0001
Total P	0.038	0.011	71%	0.31
TSS	3.85	4.31	-12%	0.84
Ammonia	0.118	0.052	56%	0.001
BOD	1.678	1.768	-5%	0.94
Copper	0.0004	0.0004	20%	0.59
Lead	0.0002	0.00004	79%	0.33
Zinc	0.016	0.024	-53%	0.0003

Note: For all pollutants, $\alpha = 0.05$
N/A = not applicable

4.7.2 Subwatershed-level Evaluation of Pollutant Removal Efficiency

For this evaluation, average storm EMCs and baseflow MCs calculated during pre-restoration conditions were compared to those calculated during post-restoration conditions at each of the three monitoring stations to compute efficiency. The pollutant removal efficiency is a straightforward method to determine the net overall benefit of restoration projects in the contributing subwatershed to each station.

Storm EMCs

The average storm EMCs of pollutants during storm events captured during pre-restoration conditions and post-restoration conditions at each station are provided in Table 4-13.

Table 4-13. Pre- and Post-Restoration Average Storm EMCs (shaded cells indicate significant results)

Pollutant (mg/L)	Phase: Pre-Restoration	Phase: Post-Restoration	Percent Efficiency	t test p-value (two-tailed)
Station WC002				
Total N	1.50	1.54	-2%	0.87
Total P	0.104	0.103	0.4%	0.99
TSS	46.84	35.46	24%	0.41
Ammonia	0.017	0.097	-464%	0.0001
BOD	2.400	4.665	-94%	0.11
Copper	0.008	0.007	9%	0.72
Lead	0.479	0.001	100%	0.33
Zinc	0.043	0.035	20%	0.26
Station WC003				
Total N	1.44	1.25	13%	0.19
Total P	0.073	0.076	-5%	0.86
TSS	28.54	31.29	-10%	0.77
Ammonia	0.030	0.091	-208%	0.04
BOD	1.585	3.410	-115%	0.09
Copper	0.006	0.007	-27%	0.39
Lead	0.000	0.001	N/A	0.002
Zinc	0.038	0.034	10%	0.53
Station WC004				
Total N	1.55	1.24	20%	0.02
Total P	0.068	0.065	4%	0.79
TSS	18.42	24.43	-33%	0.15
Ammonia	0.093	0.071	24%	0.29
BOD	2.536	3.399	-34%	0.17
Copper	0.007	0.008	-11%	0.43
Lead	0.001	0.001	-12%	0.71
Zinc	0.043	0.038	10%	0.39

Note: For all pollutants, $\alpha = 0.05$
N/A = not applicable

At Station WC002, EMCs of all parameters except total nitrogen, ammonia, and BOD were reduced from pre-restoration conditions. The reduction in lead was effectively 100%. The reductions in total phosphorus, TSS, copper, and zinc were lower, at 0.4%, 24%, 9%, and 20%, respectively. Ammonia and BOD increased dramatically, by 464% and 94% respectively, with the increase in ammonia being significant.

At Station WC003, stormflow total nitrogen and zinc decreased between pre-restoration and post-restoration conditions by 13% and 10%, respectively. BOD, ammonia, total phosphorus, and lead increased between pre- and post-restoration phases, with ammonia and lead significant. Copper and TSS increased by 27% and 10%, respectively.

At Station WC004, total nitrogen, total phosphorus, ammonia, and zinc decreased between pre-restoration and post-restoration conditions, by 20%, 4%, 24%, and 10%, respectively, with nitrogen significant. Copper, lead, BOD, and TSS increased after completion of restoration activities.

Baseflow MCs

The average baseflow MCs of pollutants during pre-restoration conditions and post-restoration conditions at each station are provided in Table 4-14.

At Station WC002 baseflow total nitrogen, copper, lead, and zinc MCs were reduced after completion of restoration projects in the contributing subwatershed. The remaining parameters increased between pre-restoration and post-restoration by 37% for BOD, 195% for TSS, and over 7 times for total phosphorus and ammonia, with ammonia showing a significant increase.

At Station WC003, baseflow data show the restoration projects in the contributing subwatershed reduced pollutants by efficiencies ranging from 24% for total nitrogen to 87% for lead, with total nitrogen and copper significant. BOD dramatically increased by over four-fold, though not significantly. Ammonia and zinc increased by 91% and 12%, respectively.

At Station WC004, baseflow efficiency results were the least ambiguous, with six of eight parameters reduced between pre-restoration conditions and post-restoration, with significant reductions for copper and zinc. Only TSS (257%) and BOD (92%) were greater during post-restoration than pre-restoration.

4.8 LONG-TERM TREND ANALYSIS OF WATER CHEMISTRY DATA

The time-series statistical tests performed on baseflow concentration and individual storm EMC data collected showed significant, downward trends for both baseflow and storm flow nitrate plus nitrite at all stations, plus stormflow zinc at Station WC002 and baseflow zinc at Station WC004. Several constituents have significantly increased over time, such as baseflow TSS at Stations WC002 and WC004, baseflow and storm flow ammonia at Stations WC002 and WC003, baseflow lead at all stations, and baseflow total phosphorus at Station WC002. While increases in baseflow TSS concentrations, along with phosphorus and metals, which adhere to particulate matter, over time are unexpected, possible contributors to increases in TSS concentrations are increases in imperviousness upstream in the watershed, lingering effects from retrofit and restoration projects, or an overall increase in baseflow due to the restorations. Overall, the results were mixed, with only 18 of the 54 EMCs and MCs examined under all flow conditions at all stations becoming lower over time. A summary of test results, including coefficients and significance, for indicator parameters is presented in Table 4-15.

Table 4-14. Pre- and Post-Restoration Average Baseflow MCs (shaded cells indicate significant results)

Pollutant (mg/L)	Phase		Percent Efficiency	t test p-value (two-tailed)
	Pre-Restoration	Post-Restoration		
Station WC002				
Total N	2.14	2.08	3%	0.74
Total P	0.006	0.047	-730%	0.23
TSS	1.38	4.07	-195%	0.07
Ammonia	0.016	0.147	-822%	<0.0001
BOD	0.900	1.229	-37%	0.58
Copper	0.001	0.0006	46%	0.28
Lead	0.0003	0.00004	87%	0.39
Zinc	0.017	0.016	7%	0.73
Station WC003				
Total N	1.88	1.44	24%	0.02
Total P	0.040	0.012	71%	0.28
TSS	3.36	2.51	25%	0.39
Ammonia	0.030	0.056	-91%	0.18
BOD	0.387	2.054	-431%	0.36
Copper	0.002	0.0005	72%	0.03
Lead	0.0003	0.00004	87%	0.29
Zinc	0.021	0.023	-12%	0.56
Station WC004				
Total N	3.49	3.25	7%	0.25
Total P	0.017	0.007	62%	0.15
TSS	0.66	2.34	-257%	0.17
Ammonia	0.052	0.016	69%	0.04
BOD	0.353	0.678	-92%	0.42
Copper	0.002	0.0005	73%	<0.0001
Lead	0.0002	0.00007	58%	0.27
Zinc	0.037	0.022	40%	0.001

Note: For all pollutants, $\alpha = 0.05$
N/A = not applicable

Table 4-15. Results of Kendall's Tau-b significance tests for indicator parameters (2010-FY2021)

Parameter	WC002		WC003		WC004	
	Storm	Baseflow	Storm	Baseflow	Storm	Baseflow
Nitrate + Nitrite	0.0037 (-)	< 0.0001 (-)	0.0003 (-)	< 0.0001 (-)	0.0001 (-)	0.0388 (-)
Total Kjeldahl Nitrogen	N.S.	< 0.0001 (+)	N.S.	< 0.0001 (+)	N.S.	0.0114 (+)
Total Phosphorus	N.S.	< 0.0001 (+)	N.S.	N.S.	N.S.	N.S.
TSS	N.S.	< 0.0001 (+)	N.S.	N.S.	N.S.	0.0097 (+)
Ammonia	< 0.0001 (+)	< 0.0001 (+)	0.0167 (+)	0.0010 (+)	N.S.	N.S.
BOD	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Copper	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Lead	N.S.	0.0060 (+)	N.S.	0.0344 (+)	N.S.	0.0495 (+)
Zinc	0.0330 (-)	N.S.	N.S.	N.S.	N.S.	0.0246 (-)

Positive (+) symbols or orange shading indicate an increasing trend over time; negative (-) symbols or green shading indicate a decreasing trend over time
N.S. = not significant

5.0 CONCLUSIONS

In a cooperative effort, Harford County DPW, Versar, and USGS conducted water chemistry and long-term flow monitoring in the Wheel Creek watershed from July 1, 2020 through June 30, 2021. The monitoring effort included twelve baseflow sampling and eight wet weather sampling events with suspended sediment transport sampling (only seven of the eight wet weather events had suspended sediment transport sampling due to contract negotiations between Harford Count DPW and the laboratory). The final wet weather event initiated on June 30, 2021, counting towards the permit requirements for Harford County, but continued until July 2, 2021. As such, discharge and chemical results fall within the next permit year and are excluded from this year's assessment; results from this storm will be included in the Year 12 report. Baseflow and stormflow monitoring consisted of sampling for suspended solids, copper, lead, zinc, BOD, ammonia, nitrate plus nitrite, chloride, orthophosphate, total phosphorous, TKN, turbidity, hardness, TPH, and *E. coli*.

5.1 SUMMARY OF MONITORING RESULTS

Federal and State reference values for certain nutrients were exceeded on several occasions, confirming detrimental stream chemistry impacts from development and changes in land use. Total nitrogen, calculated from the sum of nitrate plus nitrite and TKN, was present at concentrations exceeding the EPA reference values (0.69 mg/L) for both baseflow (all detected samples) and stormflow (96.8% of samples). For total phosphorus, 12.9% of the detectible results in baseflow samples and 87.1% of the detectible results in stormflow samples were found to be above the corresponding EPA reference concentration (0.03656 mg/L). Only one reported chloride concentration in stormflow samples exceeded the EPA acute criterion (860 mg/L), while 27.8% of baseflow samples exceeded the chronic criterion for chloride (230 mg/L).

All baseflow samples had detectable amounts of zinc but none exceeded the MDE chronic surface water criterion (120 µg/L). Of the stormflow samples, 77.8% had detectable concentrations of zinc, but none exceeded the MDE acute criterion (120 µg/L). All lead concentrations fell below the MDE acute criterion (65 µg/L) for stormflow and the chronic criterion (2.5 µg/L) for baseflow this monitoring period. Copper concentrations did not exceed the MDE chronic criterion (9 µg/L) in baseflow samples, while 4.8% of stormflow samples exceeded the acute criterion (13 µg/L).

E. coli bacteria concentrations were detected in all baseflow samples at all stations, ranging in concentration from 6.3 to 1,120 MPN/100ml. *E. coli* concentrations were equal to or greater than the maximum reportable result in 28.6% of stormflow grab samples, up from 19.0% in the FY2020 monitoring period. TPH was not detected above the reporting limit in any of the stormflow grab samples collected at the monitoring stations and was only detected in one of the baseflow grab samples collected at the monitoring stations.

Average baseflow concentrations of combined nitrate plus nitrite, chloride, zinc, and *E. coli* were highest at Station WC004 compared to the other two stations downstream. Samples collected at Station WC003 had the highest average concentrations of TPH during baseflow conditions. Station WC002 samples had the highest average concentrations of BOD, TKN, ammonia, total phosphorus, lead, copper, and TSS at baseflow. Average stormflow EMCs were highest at Station WC004 for chloride. Average EMCs for BOD, ammonia, nitrate plus nitrite, TKN, orthophosphate, and *E. coli* were highest at Station WC002. At Station WC003, TSS, copper, lead, and zinc were highest of the three stations.

Average stormflow loads were highest at Station WC002 and lowest at Station WC004 for all parameters. Since discharge volume for a given storm increases with distance downstream, maximum load results at Station WC002 are expected.

Suspended sediment transport showed a low correlation with discharge at Stations WC002 ($r^2 = 0.21$), WC003 ($r^2 = 0.23$), and WC004 ($r^2 = 0.08$). As in past monitoring periods, the sediment results have correlated better with discharge at the stations having the largest contributing watershed area.

5.2 SUMMARY OF RESTORATION EFFECTIVENESS

Comparisons of pre-restoration and post-restoration pollutant load and concentration data were performed to determine the benefit to watershed conditions as a result of the implementation of the several restoration projects. Restoration activity initiated in late summer 2012 and concluded in spring 2017, allowing a post-restoration collection of data to be accumulated. Subwatershed-level and total watershed benefits were evaluated by comparing concentration and loading data from specific stations during applicable pre-restoration and post-restoration timelines for projects within the catchments of those stations.

Comparing ratios of average concentrations and loads at Stations WC003 and WC002, determined first under pre-restoration conditions and then under post-restoration conditions, produced mixed results. Comparisons of load ratios identified only BOD, TSS, lead, zinc, and copper as being reduced by restoration. Concentration ratio results suggest that the restoration in the contributing subwatersheds has reduced total phosphorus, TSS, BOD, copper, lead, and zinc in the contributing drainage between Stations WC002 and WC003 under stormflow conditions. Under baseflow concentrations, only BOD and zinc showed improvement in terms of lowering percentage differences between the upstream and downstream stations.

Directly comparing post-restoration concentrations (both storm and baseflow) to pre-restoration concentrations showed the following: At Station WC002, storm EMCs of total phosphorus, TSS, copper, lead, and zinc were reduced from pre-restoration conditions. At Station WC003, stormflow total nitrogen and zinc decreased between pre-restoration and post-restoration conditions. At Station WC004, total nitrogen, total phosphorus, ammonia, and zinc decreased between pre-restoration and post-restoration conditions. At Station WC002 baseflow total nitrogen, copper, and lead MCs were reduced after completion of restoration projects in the contributing subwatershed. At Station WC003, baseflow concentration data show the restoration projects in the contributing subwatershed reduced total nitrogen, total phosphorus, TSS, copper, and lead. At Station WC004, baseflow efficiency results were the least ambiguous, with six of eight parameters reduced between pre-restoration conditions and post-restoration. A summary of the results of tests of restoration effectiveness is provided in Table 5-1.

Table 5-1. Results of tests of restoration effectiveness (bullets indicate pollutant reduction between post- and pre-restoration conditions)

	Target Sub-watershed	Parameter							
		BOD	Ammonia	Total P	TSS	Total N	Copper	Lead	Zinc
Ratio Loads	WC002 below WC003	●			●		●	●	●
Ratio EMC	WC002 below WC003	●		●	●		●	●	●
Ratio MC	WC002 below WC003	●							●
Before After EMC	WC002			●	●		●	●	●
Before After EMC	WC003					●			●
Before After EMC	WC004		●	●		●			●
Before After MC	WC002					●	●	●	●
Before After MC	WC003			●	●	●	●	●	
Before After MC	WC004		●	●		●	●	●	●

The time-series statistical test performed on baseflow concentration and individual storm EMC data collected showed significant, downward trends for both baseflow and storm flow nitrate plus nitrite at all stations, plus stormflow zinc at Station WC002 and baseflow zinc at Station WC004. Several constituents have significantly increased over time, such as baseflow TSS at Stations WC002 and WC004, baseflow and storm flow ammonia at Stations WC002 and WC003, baseflow lead at all stations, and baseflow total phosphorus at Station WC002. Overall, the results were mixed, with only 18 of the 54 EMCs and MCs under all flow conditions at all stations becoming lower over time. While the number of downward-trending EMCs and MCs declined compared to FY2020, the number of significantly downward-trending EMCs and MCs increased. The number of significantly upward-trending EMCs and MCs also increased, which indicates that current-year post-restoration data continue to reinforce trends in previously collected data.

Time series plots of annual average EMCs and MCs for most parameters show continuing stabilization or apparent, downward short-term trends in TSS, copper, lead, zinc, BOD and nitrate plus nitrite during the period after FY2017 and FY2018 to present. The timing of the above short-term concentration trends may indicate a cause-and-effect relationship with the completion of restoration projects in the watershed. Exceptions to the above short-term trends include ammonia, total phosphorus, and TKN, which during the past three monitoring years have been generally similar to pre- or during-construction conditions and/or trending higher. Total phosphorus, regardless of flow type, may be generally increasing in prevalence in the environment. Baseflow ammonia at Station WC002 has been trending dramatically upward since FY2017, indicating a potentially significant input from an unusual source, such as a sanitary sewer line between Stations WC002 and WC003 or within commercial and residential areas around the mainstem upstream of Station WC002. Baseflow concentrations of TKN at all stations have been gradually increasing since well-before the completion of construction.

Results of comparisons of post-restoration to pre-restoration concentrations show that effectiveness was broadest at Station WC004, followed by Stations WC002 and WC003, and mostly reflected in baseflow conditions (Table 5-1). When comparing ratios of concentrations at Stations WC002 and WC003 to isolate restoration work in contributing watersheds between the two stations, concentrations in storm runoff have been reduced for eight of 16 parameters. The results of analysis of ratios of loads show benefits in five of eight parameters. A caveat to the analysis of pollutant load is that it is highly dependent on discharge volume, so the variability in storm events that are monitored may increase the variability of load data and complicate the determination of load reduction benefit. Additionally, the change in the contractor laboratory during FY2019, and the consequential changes in reporting limits, may also affect the determination of restoration benefits when using water chemistry concentration indicators.

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APPENDIX A

STORM EVENT SUMMARY REPORTS

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

AUGUST 3-5, 2020

INTRODUCTION

Versar field staff traveled to the site on August 3 to program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 4:09 p.m. the evening of Monday, August 3. At the Wheel Creek Rain Gauge Station, 3.89 inches of rain was recorded for the duration of the storm.

On the morning of August 4, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the rising limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on August 5 to composite automated samples. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on August 5 for analysis. Per the County's request, no Siphon Samplers were deployed for this event.

The following problems occurred during the storm event:

The ISCO bubbler tubing detached at Stations WC002 and WC003 due to debris in the pipes. Versar field crew used the WC004 hydrograph to composite the two sites that were affected.

RESULTS

Hydrographs for the August 3-5 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the August 3-5 event are shown in Table A-5.

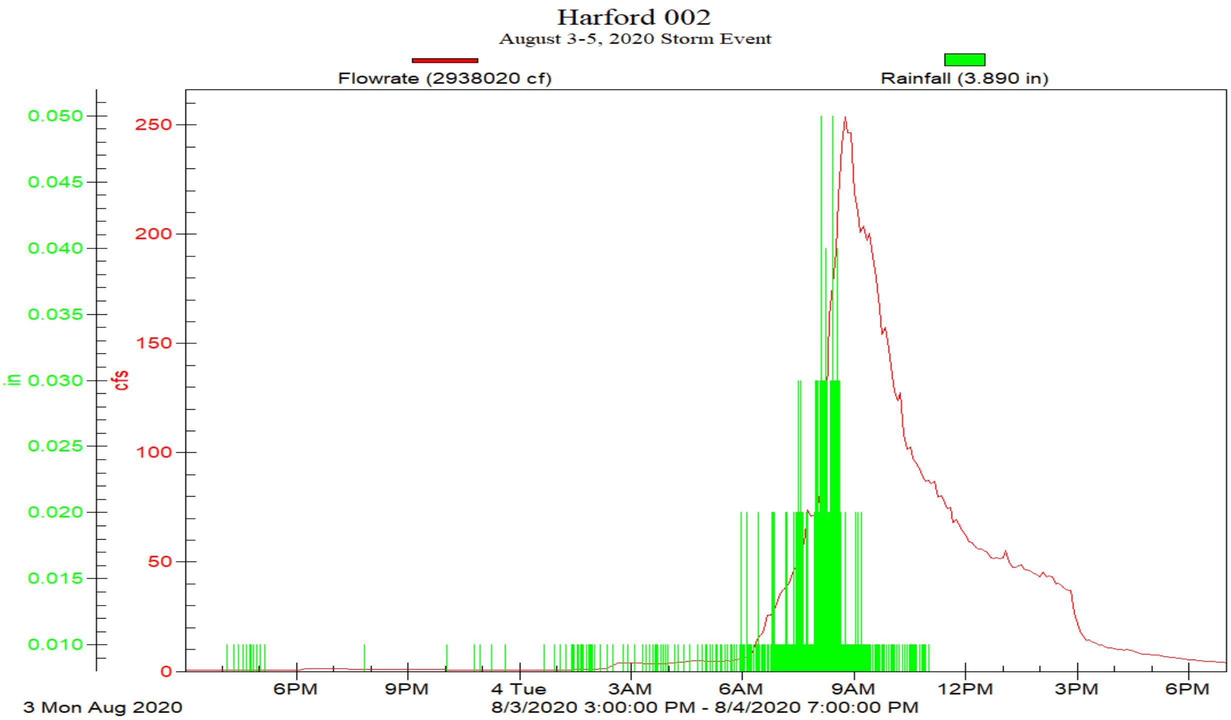

Figure A-1. Hydrograph at Station WC002 for August 3-5, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

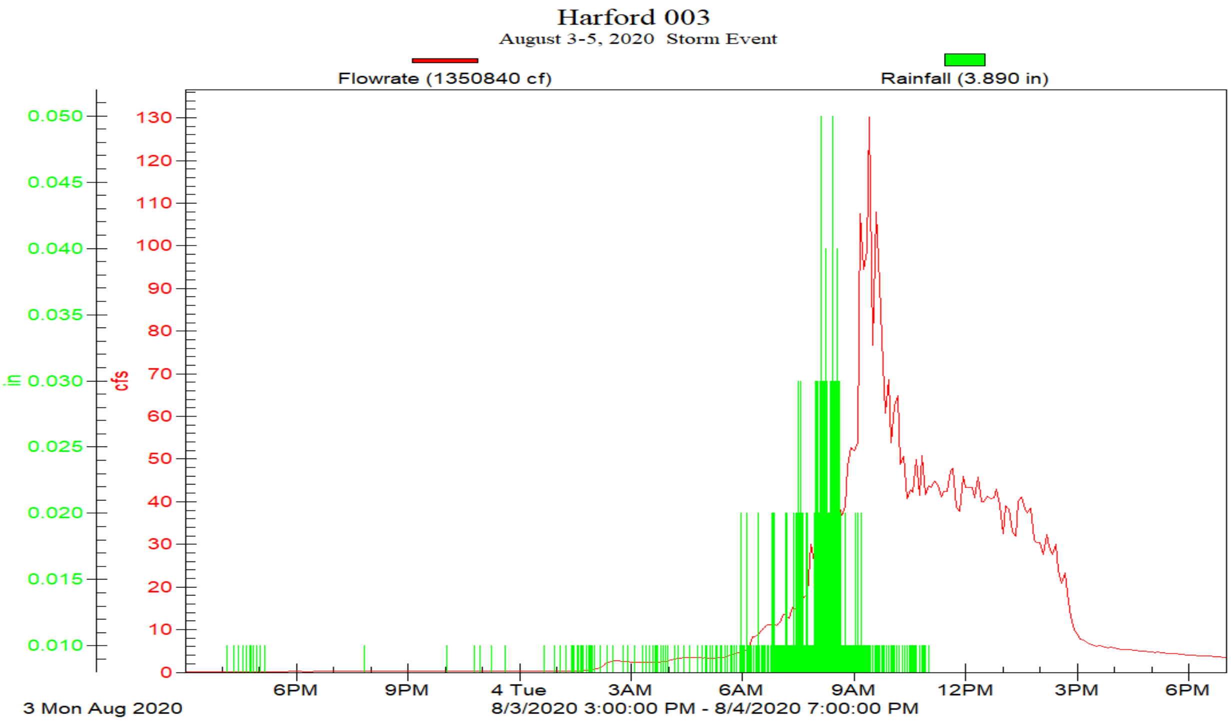

Figure A-2. Hydrograph at Station WC003 for August 3-5, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

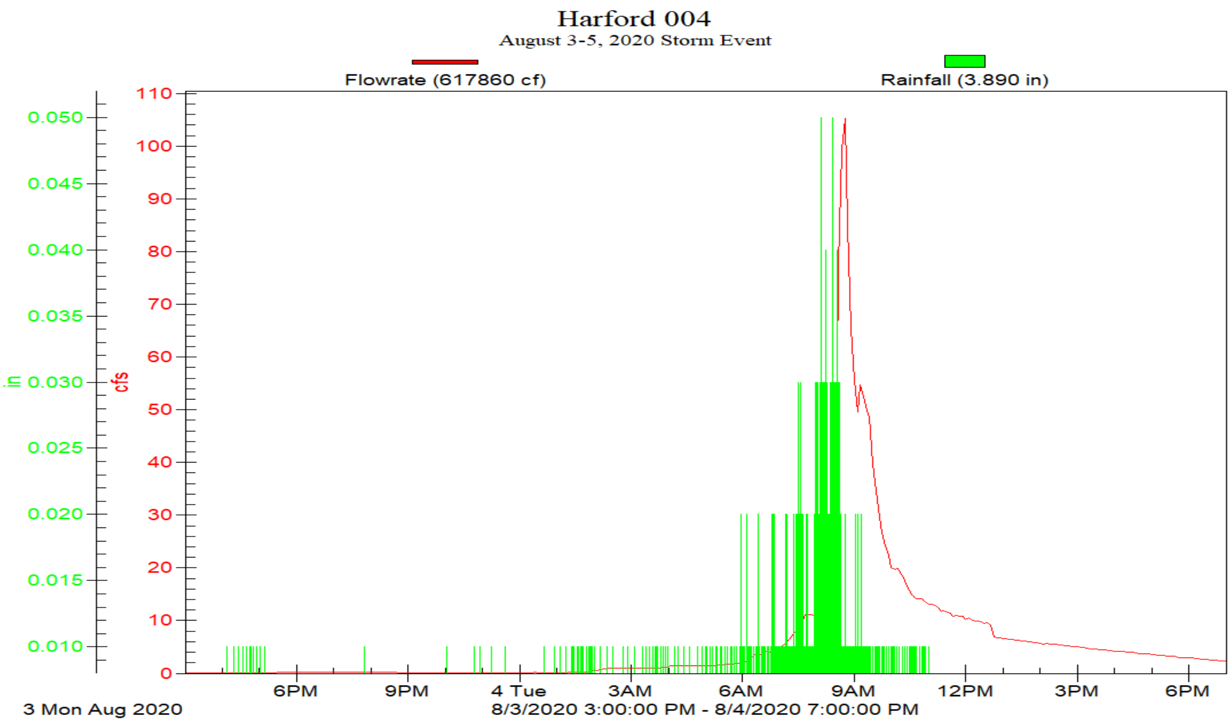

Figure A-3. Hydrograph at Station WC004 for August 3-5, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb			
Constituent	3-5-Aug-2020		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	1	2
Nitrate-Nitrite Nitrogen	0.9	0.7	0.4
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	<2	7	10
Copper	0.004	0.004	0.007
Lead	<0.001	<0.001	<0.001
Zinc	<0.010	0.012	0.020
Ammonia Nitrogen	0.12	<0.30	<0.30
Kjeldahl Nitrogen (Total)	0.4	0.5	0.6
Total Phosphorus	0.03	0.03	0.04
Hardness	124	142	78.0
Chloride	91.1	112	46.7
pH	7.02	7.04	6.48

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	3-5-Aug-2020		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2	1	1
Nitrate-Nitrite Nitrogen	0.5	0.3	0.1
Orthophosphate Phosphorus	0.03	0.02	<0.05
Solids (Suspended)	8	20	5
Copper	0.006	0.007	0.003
Lead	<0.001	<0.001	<0.001
Zinc	0.011	0.012	<0.010
Ammonia Nitrogen	<0.30	0.06	<0.30
Kjeldahl Nitrogen (Total)	0.5	0.6	0.4
Total Phosphorus	0.09	0.09	0.03
Hardness	20.0	18.0	16.0
Chloride	7.23	7.52	6.37
pH	6.85	7.26	6.71

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

Constituent	3-5-Aug-2020 Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	1	1
Nitrate-Nitrite Nitrogen	0.6	0.3	0.2
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	3	10	3
Copper	0.004	0.004	0.003
Lead	<0.001	<0.001	<0.001
Zinc	<0.010	<0.010	<0.010
Ammonia Nitrogen	<0.30	0.06	<0.30
Kjeldahl Nitrogen (Total)	0.5	0.4	0.6
Total Phosphorus	0.05	0.04	0.03
Hardness	66.0	38.0	34.0
Chloride	33.0	22.3	18.4
pH	6.83	7.01	6.6

Table A-4. Analytical Results – Wheel Creek Grab Sampling

Constituent	Station WC002	Station WC003	Station WC004
August 4, 2020 (Rising)			
TPH (mg/L)	<5.0	<5.0	<5.0
E. coli (MPN/100 ml)	2420	1990	249
Temp (C)	24.2	24	23.2
DO (mg/L)	6.51	6.25	5.02
pH	6.37	6.4	6.11
Sp. Cond. (mS/cm)	0.458	0.48	0.69

Table A-5. Rainfall and flow statistics

Constituent	Station WC002	Station WC003	Station WC004
Rainfall (in.)	3.89	3.89	3.89
Duration (hrs.)	28	28	28
Intensity (in./hr.)	0.139	0.139	0.139
Discharge (cf.)	2,938,020	1,350,840	617,860

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

SEPTEMBER 10-11, 2020

INTRODUCTION

Versar field staff traveled to the site on September 9 to deploy siphon samplers and program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 3:15 p.m. the afternoon of Wednesday, September 10. At the Wheel Creek Rain Gauge Station, 0.34 inches of rain was recorded for the duration of the storm.

On the morning of September 11, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on September 11 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on September 11. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on September 11. Laboratory staff broke one of the TPH samples in transit, resulting in no TPH results for Station WC004 for this event.

RESULTS

Hydrographs for the September 10-11 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the September 10-11 event are shown in Table A-5.

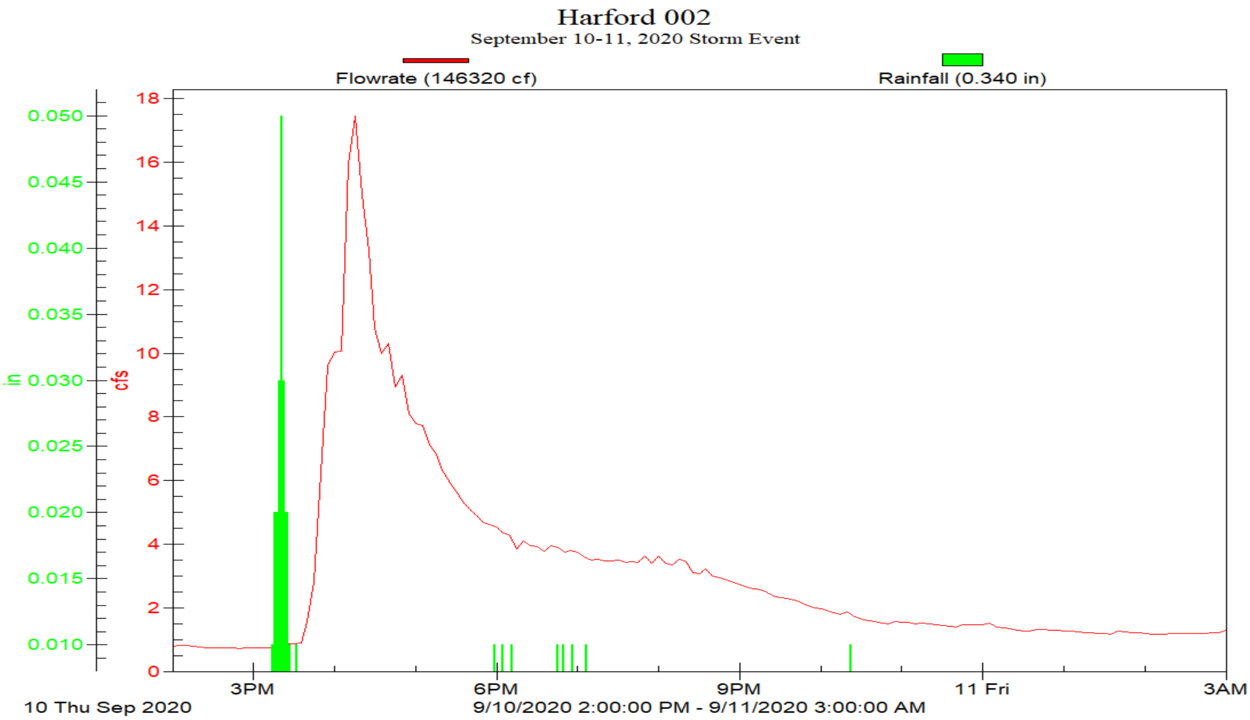

Figure A-1. Hydrograph at Station WC002 for September 10-11, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

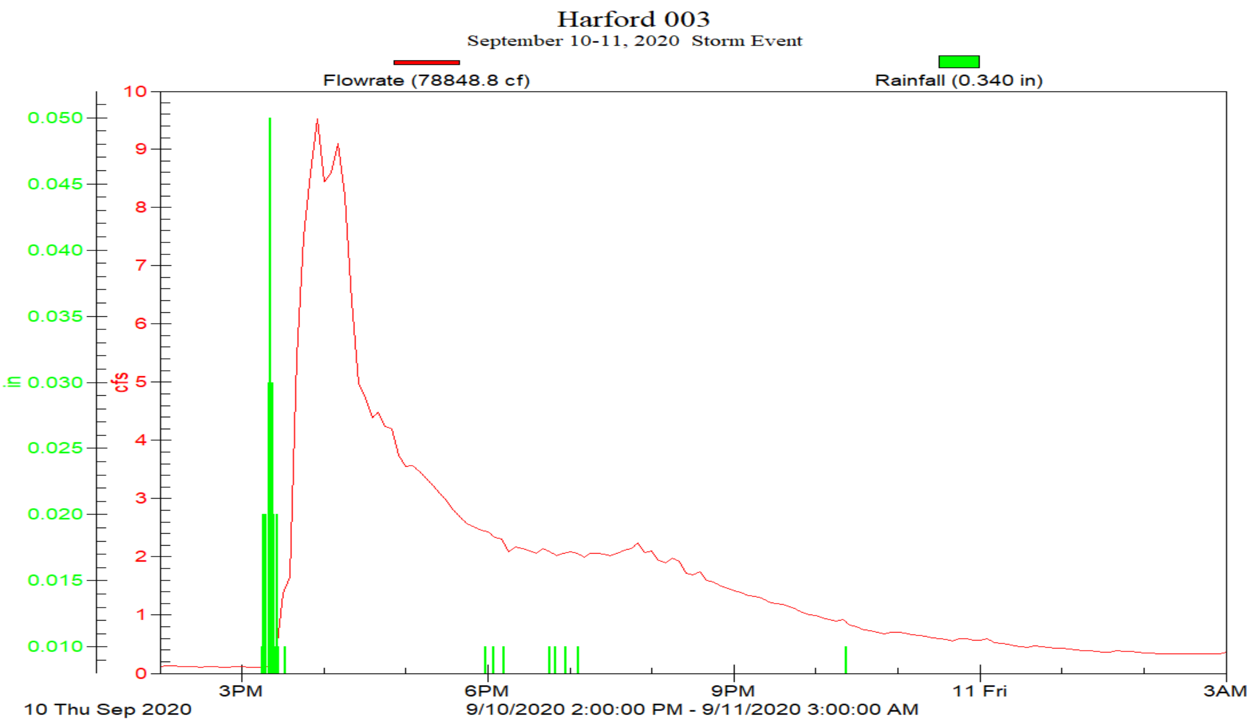

Figure A-2. Hydrograph at Station WC003 for September 10-11, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

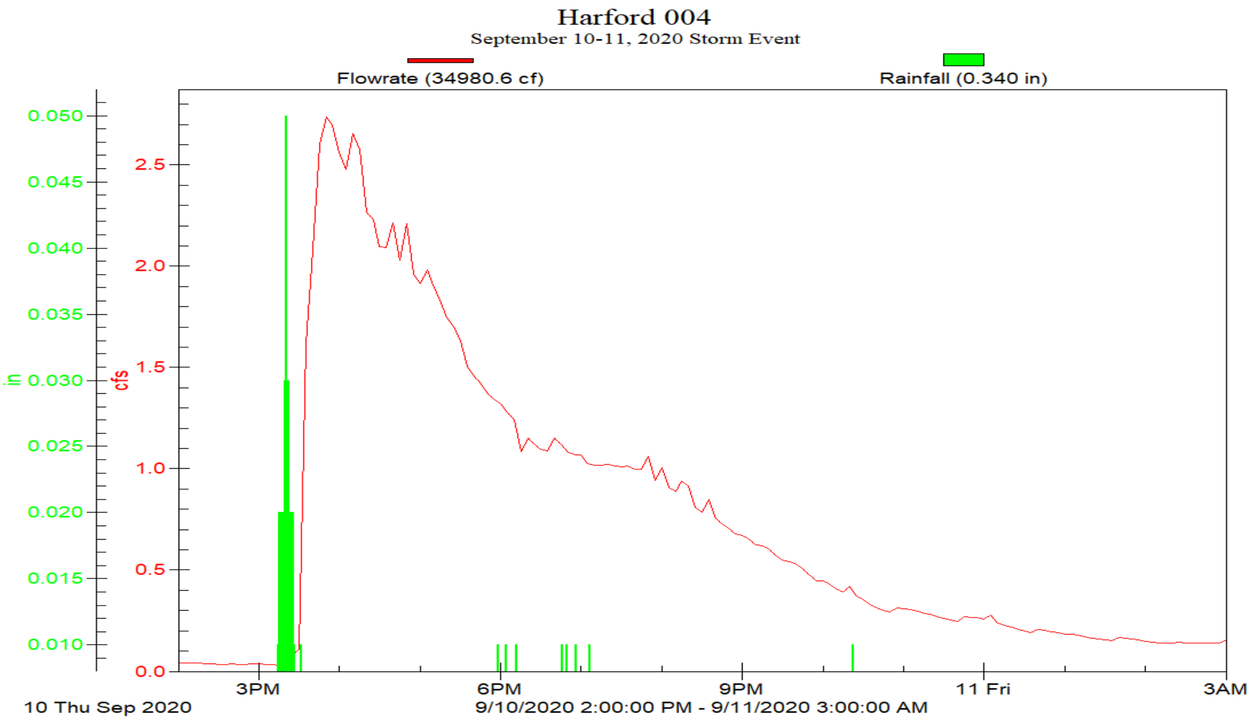

Figure A-3. Hydrograph at Station WC004 for September 10-11, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	10-11-Sep-2020		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	<1	3
Nitrate-Nitrite Nitrogen	1.1	0.8	0.9
Orthophosphate Phosphorus	<0.05	<0.05	0.03
Solids (Suspended)	<2	<2	61
Copper	0.002	0.002	0.011
Lead	<0.001	<0.001	0.003
Zinc	<0.010	<0.010	0.044
Ammonia Nitrogen	0.08	0.13	0.11
Kjeldahl Nitrogen (Total)	0.4	0.5	1.1
Total Phosphorus	0.03	0.02	0.24
Hardness	144	140	122
Chloride	99.9	111	82.3
pH	7.31	7.46	7.12

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

Constituent	10-11-Sep-2020		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	4	4	3
Nitrate-Nitrite Nitrogen	0.4	0.3	0.2
Orthophosphate Phosphorus	0.02	0.03	0.01
Solids (Suspended)	33	47	27
Copper	0.009	0.011	0.007
Lead	0.001	0.003	<0.002
Zinc	0.024	0.052	0.026
Ammonia Nitrogen	0.08	0.24	0.07
Kjeldahl Nitrogen (Total)	0.8	1.1	0.8
Total Phosphorus	0.14	0.20	0.10
Hardness	56.0	52.0	26.0
Chloride	31.6	31.0	18.9
pH	7.32	7.28	7.28

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	10-11-Sep-2020		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2	2	3
Nitrate-Nitrite Nitrogen	0.3	0.5	0.3
Orthophosphate Phosphorus	<0.05	0.01	<0.05
Solids (Suspended)	5	3	9
Copper	0.004	0.004	0.009
Lead	<0.001	<0.001	<0.002
Zinc	<0.010	<0.010	0.032
Ammonia Nitrogen	0.06	0.15	0.06
Kjeldahl Nitrogen (Total)	0.6	0.5	0.6
Total Phosphorus	0.05	0.05	0.05
Hardness	70.0	60.0	56.0
Chloride	42.1	38.5	40.9
pH	7.36	7.33	7.18

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	Station WC002	Station WC003	Station WC004
September 11, 2020 (Falling)			
TPH (mg/L)	<5.0	<5.0	NS
E. coli (MPN/100 ml)	1990	1550	517
Temp (C)	22.6	23	23.6
DO (mg/L)	7.77	7.78	4.91
pH	7.06	7.22	7.33
Sp. Cond. (mS/cm)	0.309	0.292	0.253
NS – No sample; laboratory broke the sample bottle in transit			

Table A-5. Rainfall and flow statistics			
Constituent	Station WC002	Station WC003	Station WC004
Rainfall (in.)	0.34	0.34	0.34
Duration (hrs.)	13	13	13
Intensity (in./hr.)	0.026	0.026	0.026
Discharge (cf.)	146,320	78,849	34,981

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

NOVEMBER 11-12, 2020

INTRODUCTION

Versar field staff traveled to the site on November 10 to deploy siphon samplers and program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 10:42 a.m. the morning of Wednesday, November 11. At the Wheel Creek Rain Gauge Station, 2.15 inches of rain was recorded for the duration of the storm.

On the evening of November 11, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the peak limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on November 13 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on November 13. Composite samples, including TPH samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on September 13.

The following problems occurred during the storm event:

The ISCO bubbler tubing detached at Stations WC002 and WC003 due to debris in the pipes. Versar field crew used the WC004 hydrograph to composite the two sites that were affected. Flush samples were collected during the composite visit due to the setup for the storm setup falling on a holiday.

RESULTS

Hydrographs for the November 11-12 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the November 11-12 storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the event are shown in Table A-5.

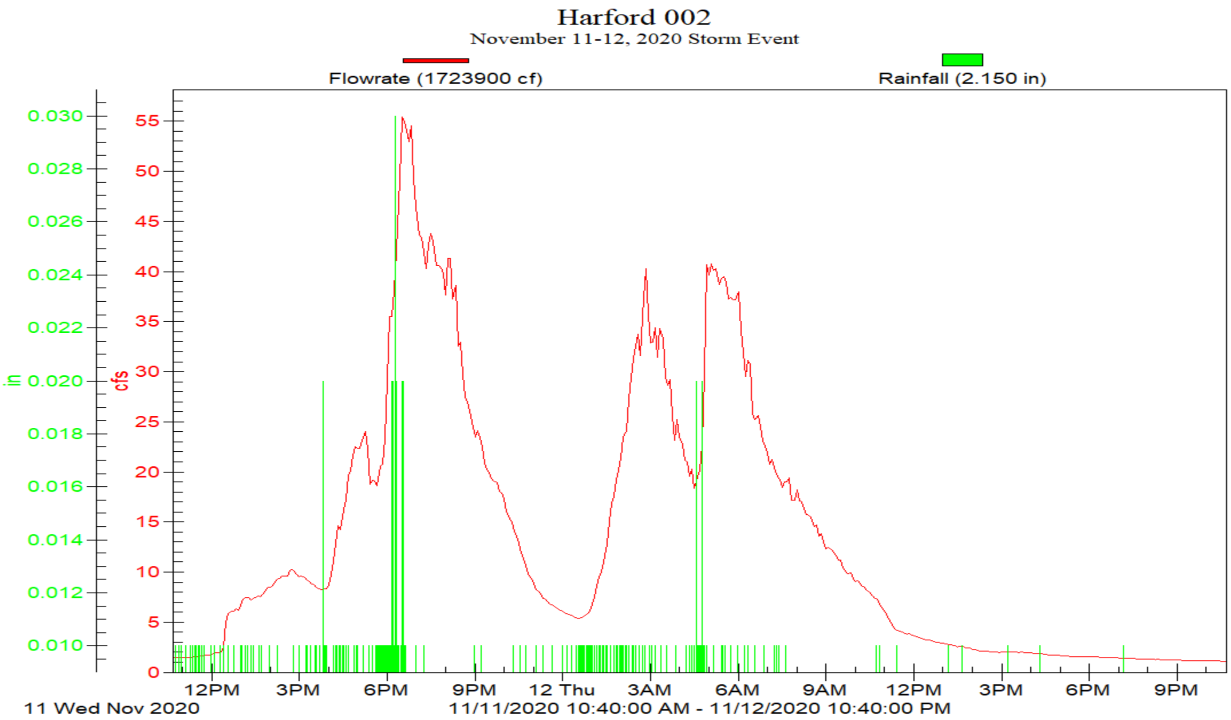

Figure A-1. Hydrograph at Station WC002 for November 11-12, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

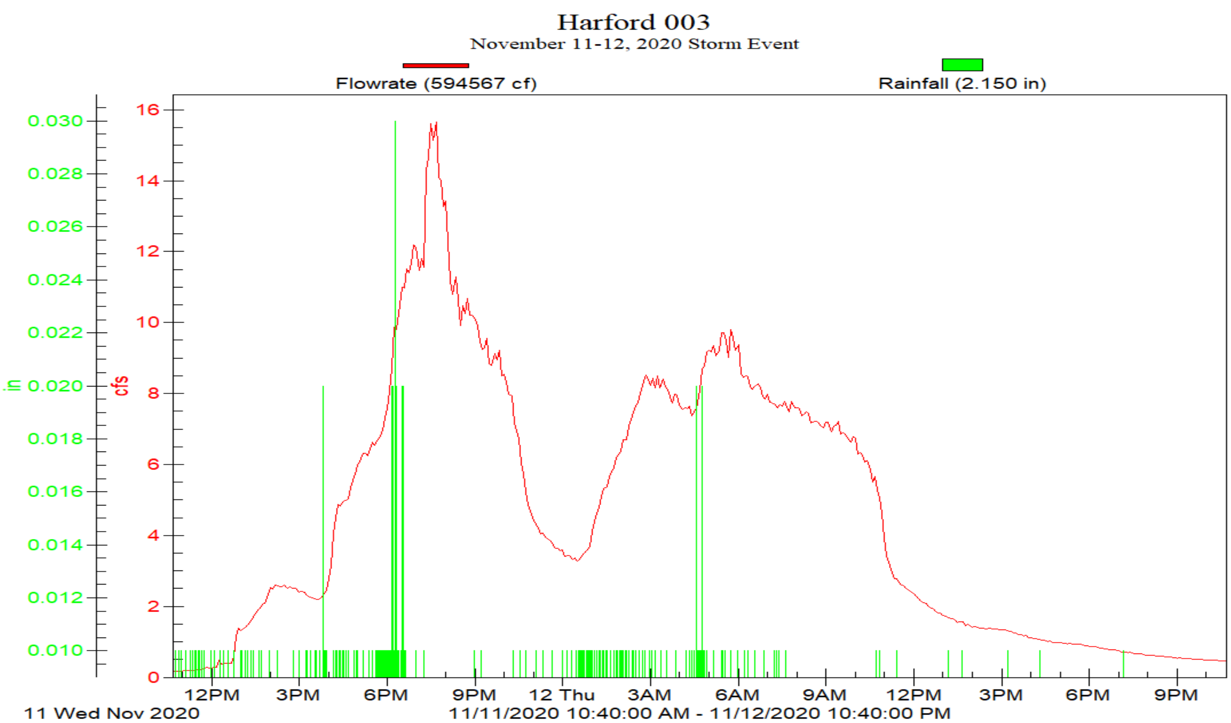

Figure A-2. Hydrograph at Station WC003 for November 11-12, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

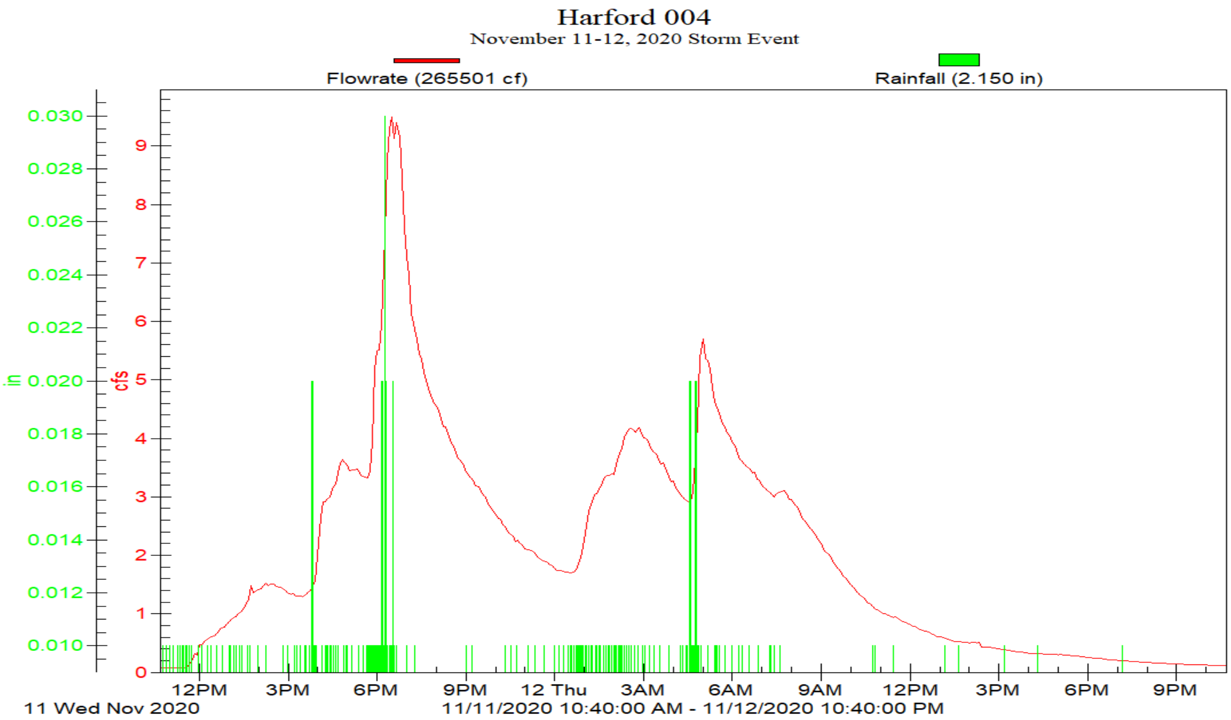

Figure A-3. Hydrograph at Station WC004 for November 11-12, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb			
Constituent	11-12-Nov-2020		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	7	4	4
Nitrate-Nitrite Nitrogen	0.5	0.6	0.3
Orthophosphate Phosphorus	0.01	<0.05	0.01
Solids (Suspended)	18	19	16
Copper	0.006	<0.004	0.010
Lead	<0.002	<0.002	<0.001
Zinc	0.021	<0.020	0.025
Ammonia Nitrogen	0.08	0.09	0.07
Kjeldahl Nitrogen (Total)	0.9	0.8	0.9
Total Phosphorus	0.08	0.05	0.07
Hardness	112	130	102
Chloride	72.0	93.8	26.6
pH	7.23	7.28	7.43

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	11-12-Nov-2020		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	4	3	2
Nitrate-Nitrite Nitrogen	0.4	0.3	0.2
Orthophosphate Phosphorus	0.05	0.02	<0.05
Solids (Suspended)	22	19	5
Copper	0.006	0.006	0.004
Lead	<0.002	<0.002	<0.001
Zinc	<0.020	0.024	0.012
Ammonia Nitrogen	<0.30	0.07	0.06
Kjeldahl Nitrogen (Total)	0.9	0.8	0.5
Total Phosphorus	0.13	0.09	0.04
Hardness	44.0	26.0	28.0
Chloride	12.9	21.5	10.1
pH	7.48	7.49	7.47

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	**11-12-Nov-2020**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	2	2	1
Nitrate-Nitrite Nitrogen	0.8	0.4	0.4
Orthophosphate Phosphorus	0.02	0.02	<0.05
Solids (Suspended)	4	4	3
Copper	0.005	<0.004	0.004
Lead	<0.001	<0.002	<0.001
Zinc	0.016	<0.020	0.014
Ammonia Nitrogen	<0.30	0.10	0.25
Kjeldahl Nitrogen (Total)	0.7	0.6	0.6
Total Phosphorus	0.05	0.04	0.03
Hardness	72.0	44.0	56.0
Chloride	38.0	37.5	29.8
pH	7.35	7.45	7.24

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
November 12, 2020 (Peak)			
TPH (mg/L)	<5.0	<5.0	<5.0
E. coli (MPN/100 ml)	>2420	2420	2420
Temp (C)	15.8	15.6	16.3
DO (mg/L)	9.16	8.76	8.41
pH	7.63	7.57	7.33
Sp. Cond. (mS/cm)	0.183	0.18	0.137

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	2.15	2.15	2.15
Duration (hrs.)	36	36	36
Intensity (in./hr.)	0.060	0.060	0.060
Discharge (cf.)	1,723,900	594,567	265,501

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

DECEMBER 14, 2020

INTRODUCTION

Versar field staff traveled to the site on December 13 to deploy siphon samplers and program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 6:57 a.m. the morning of Monday, December 14. At the Wheel Creek Rain Gauge Station, 0.98 inches of rain was recorded for the duration of the storm.

On the morning of December 14, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the peak limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on December 15 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on December 15. Composite samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on December 15.

RESULTS

Hydrographs for the December 14 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the December 14 event are shown in Table A-5.

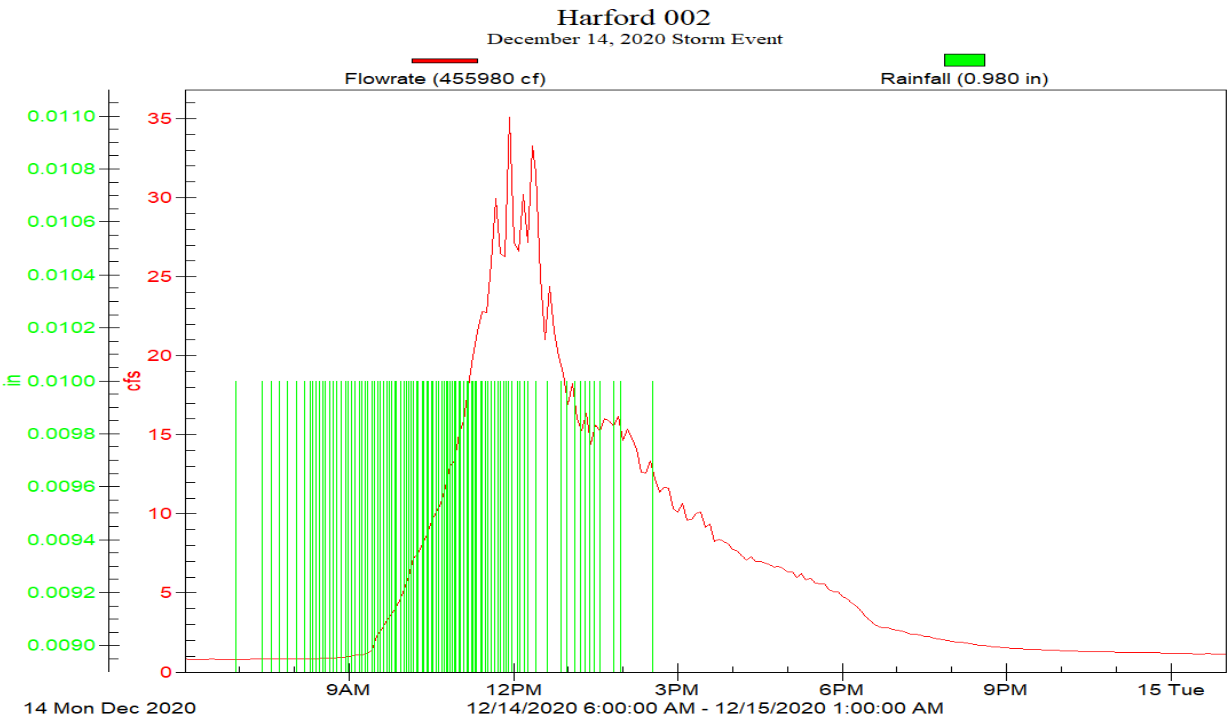

Figure A-1. Hydrograph at Station WC002 for December 14, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

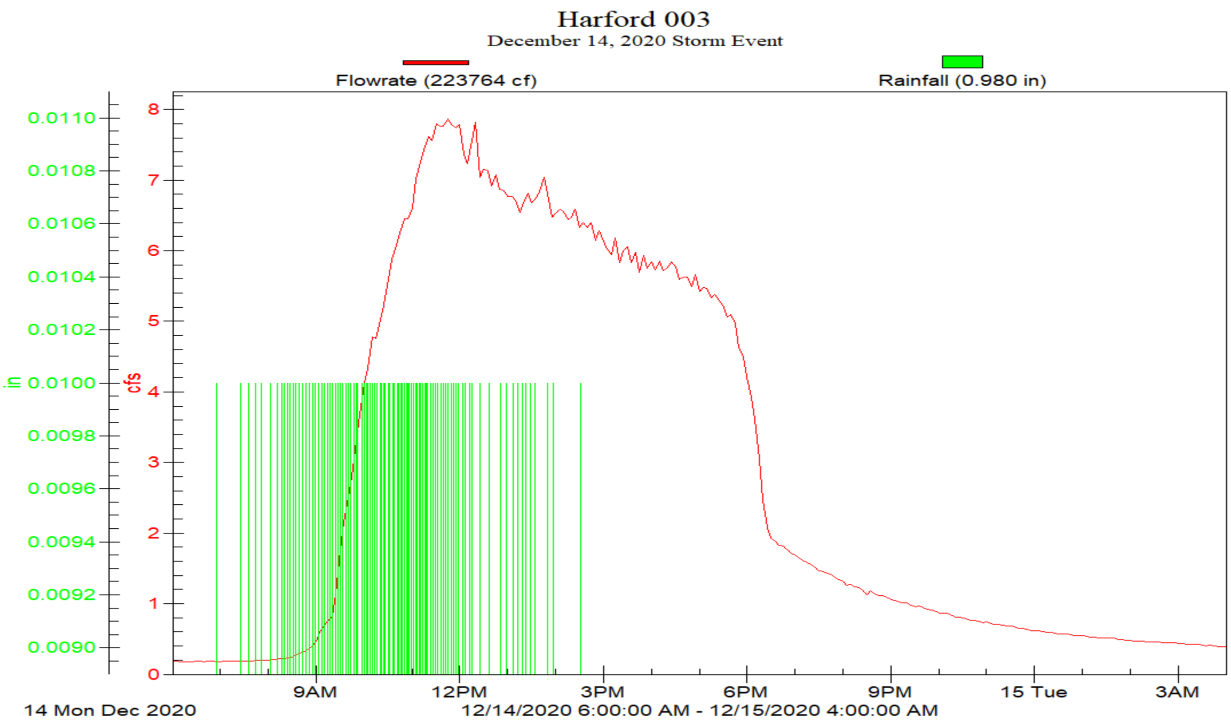

Figure A-2. Hydrograph at Station WC003 for December 14, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

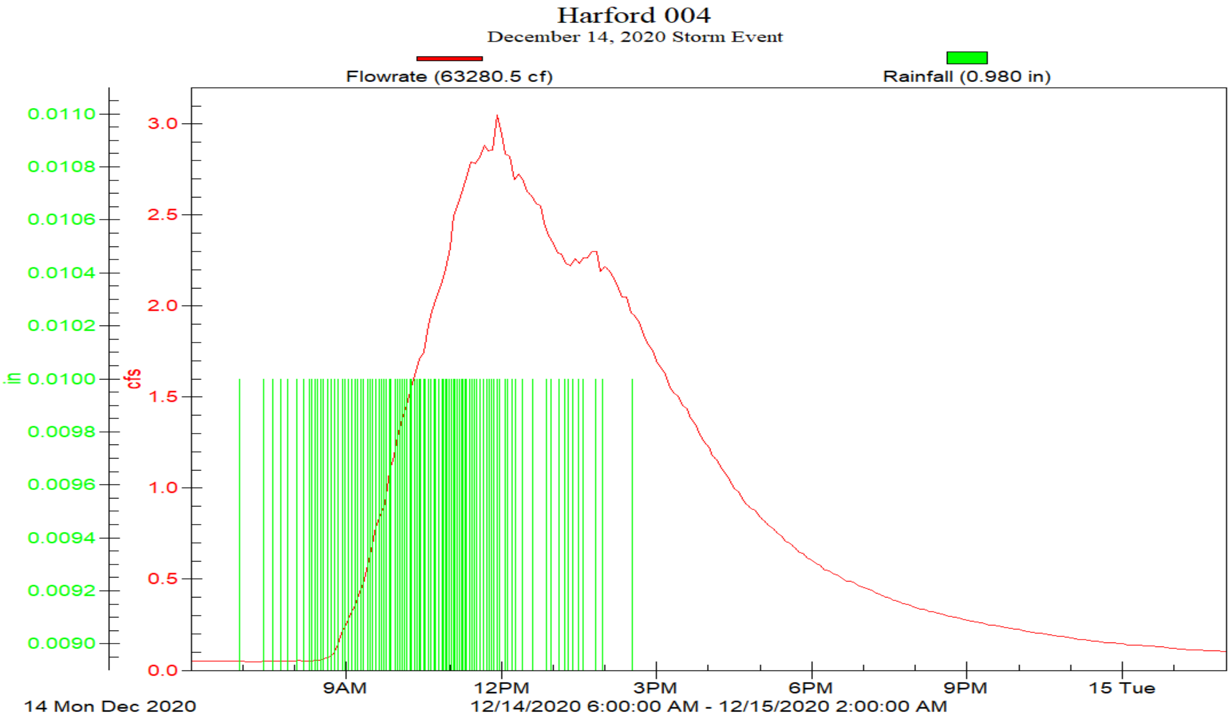

Figure A-3. Hydrograph at Station WC004 for December 14, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb			
Constituent	**14-Dec-2020**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	2	2	2
Nitrate-Nitrite Nitrogen	0.4	0.4	0.7
Orthophosphate Phosphorus	0.05	0.02	0.07
Solids (Suspended)	28	34	22
Copper	0.007	0.007	0.007
Lead	0.002	0.001	0.001
Zinc	0.023	0.023	0.031
Ammonia Nitrogen	0.36	0.12	0.11
Kjeldahl Nitrogen (Total)	0.8	0.8	0.8
Total Phosphorus	0.16	0.12	0.08
Hardness	38.0	62.0	22.0
Chloride	20.9	34.8	49.3
pH	7.56	7.38	7.42

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	**14-Dec-2020**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	2	2	1
Nitrate-Nitrite Nitrogen	0.3	0.2	0.2
Orthophosphate Phosphorus	0.05	0.02	0.02
Solids (Suspended)	22	15	8
Copper	0.007	0.006	0.005
Lead	<0.002	<0.002	<0.001
Zinc	<0.020	<0.020	0.016
Ammonia Nitrogen	0.18	0.08	0.08
Kjeldahl Nitrogen (Total)	0.7	0.6	0.6
Total Phosphorus	0.14	0.08	0.05
Hardness	38.0	36.0	26.0
Chloride	11.8	16.2	9.57
pH	7.58	7.5	7.69

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	**14-Dec-2020**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	2	1	<1
Nitrate-Nitrite Nitrogen	0.4	0.4	0.2
Orthophosphate Phosphorus	0.04	0.06	<0.05
Solids (Suspended)	11	6	3
Copper	0.006	0.005	0.005
Lead	<0.001	<0.001	<0.001
Zinc	0.014	0.014	0.028
Ammonia Nitrogen	0.23	0.08	0.06
Kjeldahl Nitrogen (Total)	0.6	0.5	0.5
Total Phosphorus	0.09	0.05	0.03
Hardness	44.0	56.0	32.0
Chloride	25.9	35.9	23.4
pH	7.48	7.4	7.46

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
December 14, 2020 (Peak)			
TPH (mg/L)	<5.0	<5.0	<5.0
E. coli (MPN/100 ml)	>2420	2420	1990
Temp (C)	6.5	6.5	6.4
DO (mg/L)	12.1	12	11.84
pH	8.28	7.89	7.74
Sp. Cond. (mS/cm)	0.101	0.157	0.102

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	0.98	0.98	0.98
Duration (hrs.)	19	22	20
Intensity (in./hr.)	0.052	0.045	0.049
Discharge (cf.)	455,980	2,237,649	632,805

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

FEBRUARY 15-16, 2021

INTRODUCTION

Versar field staff traveled to the site on February 15 to deploy siphon samplers and program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 10:39 p.m. the evening of Monday, February 15. At the Wheel Creek Rain Gauge Station, 0.81 inches of rain was recorded for the duration of the storm.

On the morning of February 16, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on February 16 to composite automated samples and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on February 16. Composite samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on February 16.

The following problems occurred during the storm event:

The ISCO bubbler tubing detached at Station WC002 due to debris in the pipe. Versar field crew used the WC003 hydrograph to composite the storm for that site.

RESULTS

Hydrographs for the February 15-16 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the February 15-16 event are shown in Table A-5.

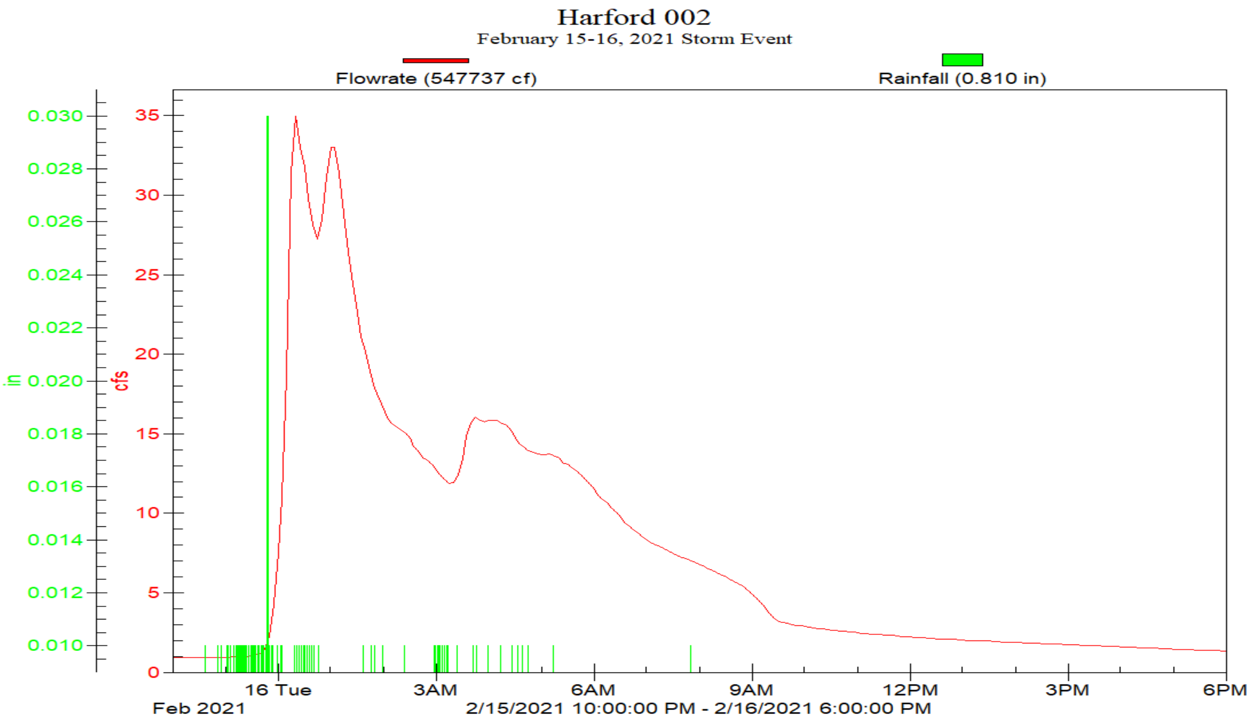

Figure A-1. Hydrograph at Station WC002 for February 15-16, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

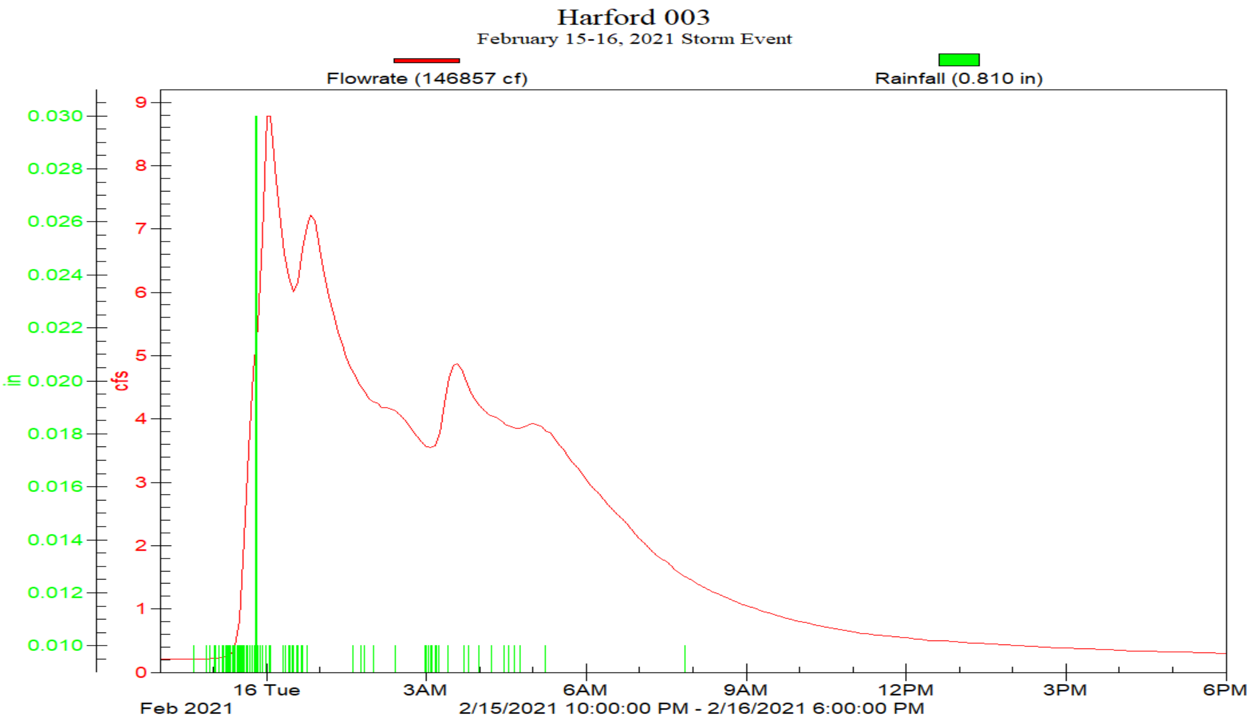

Figure A-2. Hydrograph at Station WC003 for February 15-16, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

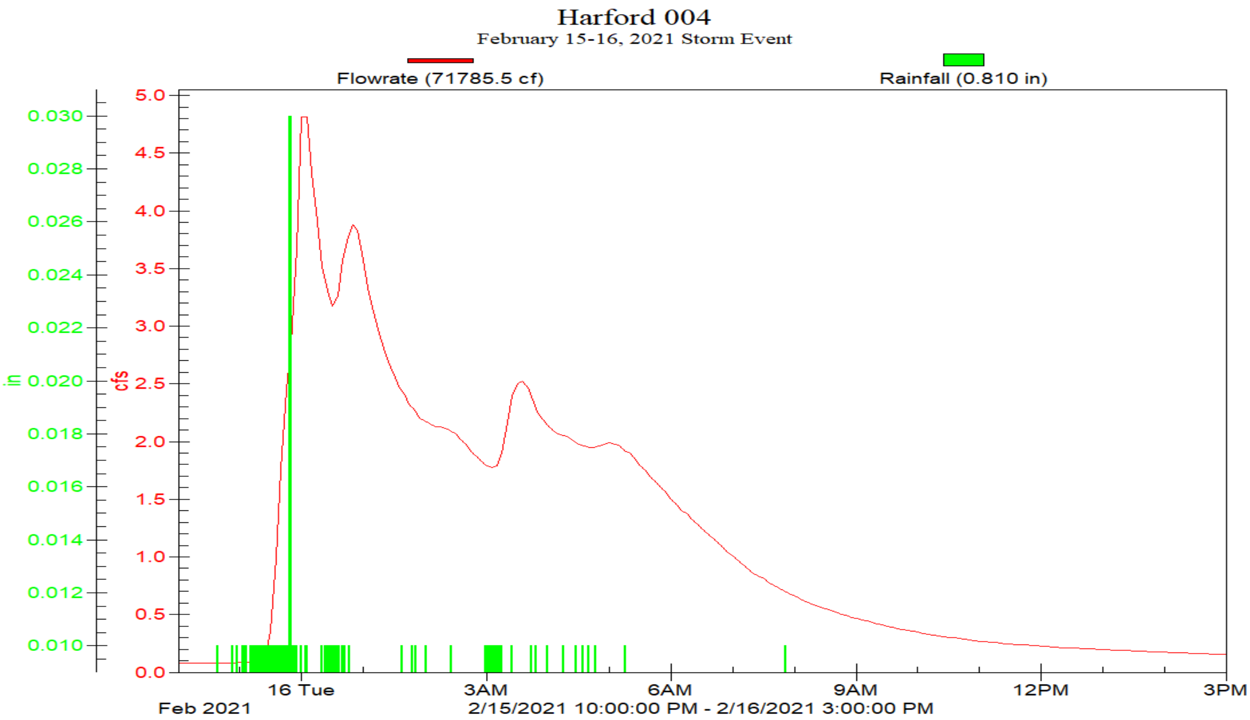

Figure A-3. Hydrograph at Station WC004 for February 15-16, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	15-16-Feb-2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	6	5	4
Nitrate-Nitrite Nitrogen	0.7	0.6	0.7
Orthophosphate Phosphorus	0.15	0.12	0.04
Solids (Suspended)	99	155	83
Copper	0.016	0.016	0.014
Lead	0.005	0.005	0.004
Zinc	0.093	0.101	0.116
Ammonia Nitrogen	0.25	0.19	0.20
Kjeldahl Nitrogen (Total)	1.8	1.7	1.3
Total Phosphorus	0.33	0.31	0.18
Hardness	98.0	142	124
Chloride	566	778	796
pH	7.32	7.43	7.25

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

Constituent	15-16-Feb-2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	4	3	3
Nitrate-Nitrite Nitrogen	0.5	0.4	0.3
Orthophosphate Phosphorus	0.12	0.06	0.04
Solids (Suspended)	67	55	23
Copper	0.009	0.008	0.007
Lead	0.002	0.002	0.002
Zinc	0.064	0.055	0.054
Ammonia Nitrogen	0.28	0.33	0.19
Kjeldahl Nitrogen (Total)	1.2	1.0	0.7
Total Phosphorus	0.21	0.16	0.11
Hardness	64.0	80.0	56.0
Chloride	378	547	733
pH	7.41	7.53	7.47

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

Constituent	15-16-Feb-2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2	2	2
Nitrate-Nitrite Nitrogen	0.5	0.4	0.4
Orthophosphate Phosphorus	0.04	0.02	0.01
Solids (Suspended)	12	19	16
Copper	0.005	0.007	0.004
Lead	<0.001	0.001	<0.001
Zinc	0.031	0.035	0.040
Ammonia Nitrogen	0.15	0.12	0.14
Kjeldahl Nitrogen (Total)	0.7	0.7	0.5
Total Phosphorus	0.09	0.08	0.05
Hardness	84.0	102	60.0
Chloride	459	622	655
pH	7.34	7.37	7.42

Table A-4. Analytical Results – Wheel Creek Grab Sampling

Constituent	Station WC002	Station WC003	Station WC004
February 16, 2021 (Falling)			
TPH (mg/L)	<5.0	<5.0	<5.0
E. coli (MPN/100 ml)	613	119	41.4
Temp (C)	4.41	5	5.6
DO (mg/L)	12.69	12.36	12.26
pH	7.77	7.38	7.34
Sp. Cond. (mS/cm)	1.22	1.527	2.103

Table A-5. Rainfall and flow statistics

Constituent	Station WC002	Station WC003	Station WC004
Rainfall (in.)	0.81	0.81	0.81
Duration (hrs.)	20	20	17
Intensity (in./hr.)	0.041	0.041	0.048
Discharge (cf.)	547,737	146,857	71,785

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

MARCH 18-19, 2021

INTRODUCTION

Versar field staff traveled to the site on March 17 to deploy siphon samplers and program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 5:51 a.m. the morning of Thursday, March 18. At the Wheel Creek Rain Gauge Station, 0.81 inches of rain was recorded for the duration of the storm.

On the morning of March 19, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on March 19 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on March 19. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on March 19.

The following issue occurred during the storm event:

The ISCO bubbler line detached from the sensor carrier at Station WC002 station during the storm event due to debris in the pipe. Station WC003 station also had issues with debris in the pipe that caused both the sensor carrier and tubing to be completely detached from the pipe. Versar field crew used the WC004 hydrograph to composite the storm at both affected sites.

RESULTS

Hydrographs for the March 18-19 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the March 18-19 event are shown in Table A-5.

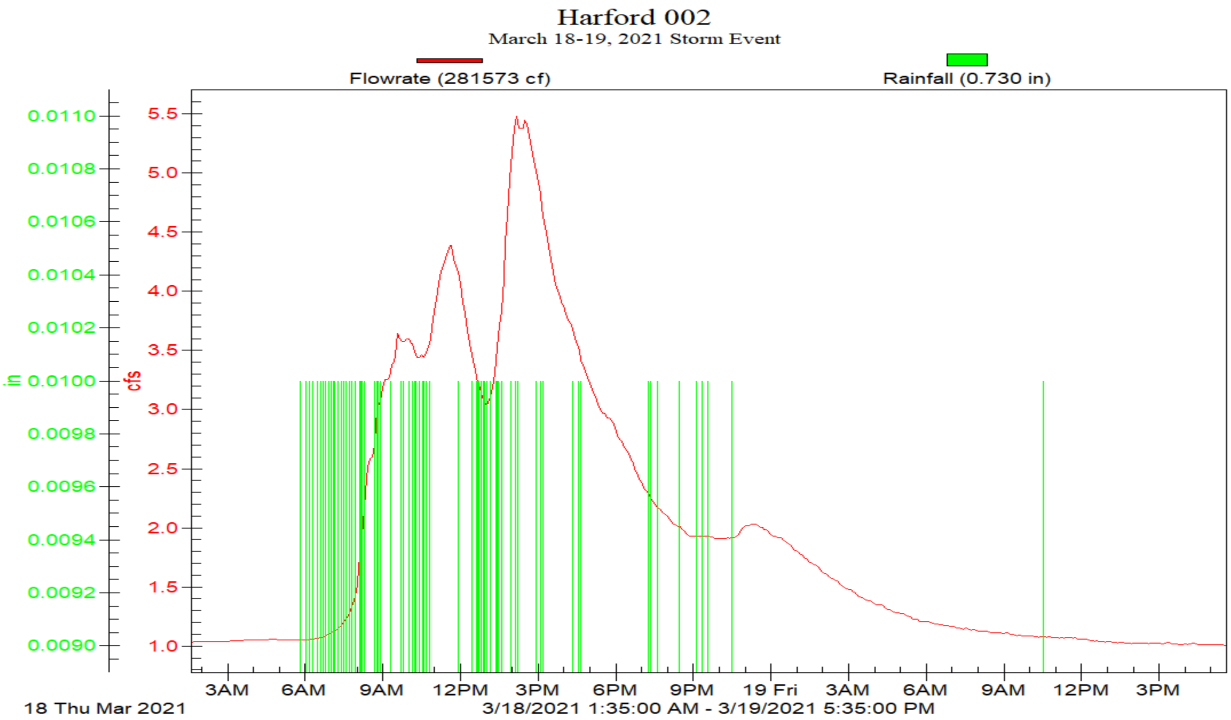

Figure A-1. Hydrograph at Station WC002 for March 18-19, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

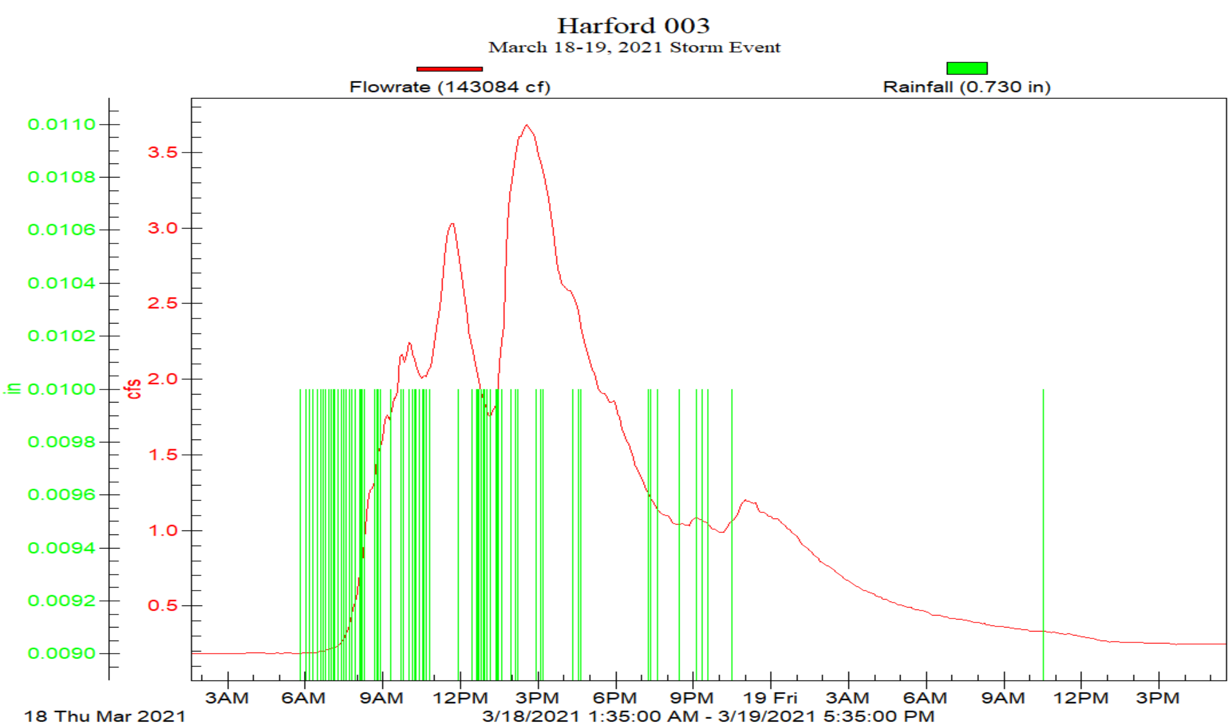

Figure A-2. Hydrograph at Station WC003 for March 18-19, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

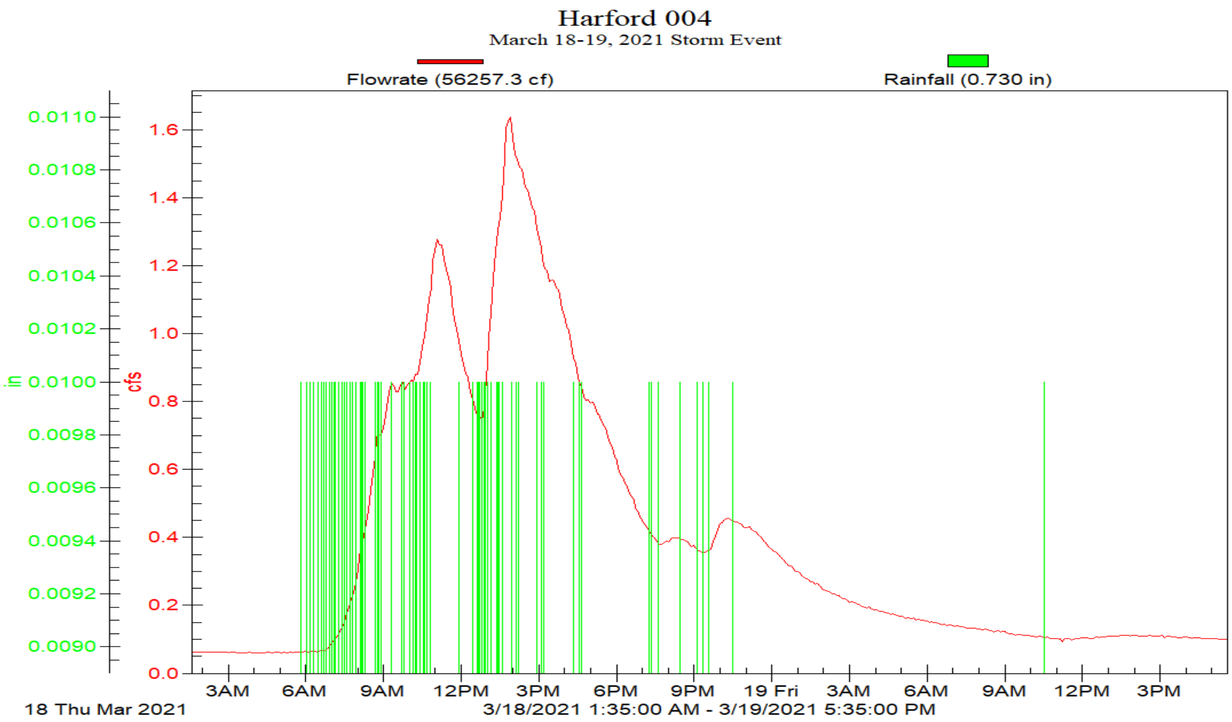

Figure A-3. Hydrograph at Station WC004 for March 18-19, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	18-19-Mar-2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2.2	2.2	3.6
Nitrate-Nitrite Nitrogen	1.62	1.22	1.62
Orthophosphate Phosphorus	<0.02	<0.02	<0.02
Solids (Suspended)	6.8	42.0	32.8
Copper	<0.002	0.003	0.001
Lead	0.0002	0.001	0.001
Zinc	0.017	0.033	0.057
Ammonia Nitrogen	<0.10	<0.10	<0.10
Kjeldahl Nitrogen (Total)	<0.50	<0.50	0.90
Total Phosphorus	0.11	0.13	0.10
Hardness	146	162	189
Chloride	205	291	972
pH	6.97	7.19	7.07

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

Constituent	18-19-Mar-2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2.9	2.9	3.4
Nitrate-Nitrite Nitrogen	0.58	0.50	0.31
Orthophosphate Phosphorus	<0.02	<0.02	0.02
Solids (Suspended)	15.2	23.6	20.0
Copper	0.005	0.007	0.004
Lead	0.0006	0.001	0.001
Zinc	0.028	0.030	0.044
Ammonia Nitrogen	0.11	<0.10	0.14
Kjeldahl Nitrogen (Total)	0.60	0.90	0.92
Total Phosphorus	0.10	0.11	0.16
Hardness	60.0	87.0	54.0
Chloride	206	328	370
pH	7.22	7.3	7.37

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	**18-19-Mar-2021**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	<2.0	<2.0	2.3
Nitrate-Nitrite Nitrogen	0.99	0.76	0.64
Orthophosphate Phosphorus	<0.02	<0.02	0.07
Solids (Suspended)	<4.0	5.2	6.5
Copper	0.001	0.001	0.003
Lead	0.0002	0.0004	0.0006
Zinc	0.019	0.021	0.035
Ammonia Nitrogen	<0.10	<0.10	0.11
Kjeldahl Nitrogen (Total)	<0.50	<0.50	<0.50
Total Phosphorus	<0.10	0.10	0.11
Hardness	90.0	96.0	76.0
Chloride	209	310	367
pH	7.15	7.26	7.21

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
March 19, 2021 (Falling)			
TPH (mg/L)	<5.0	<5.0	<5.0
E. coli (MPN/100 ml)	86.2	93.3	488
Temp (C)	8.4	8.6	9.2
DO (mg/L)	12.29	11.39	10.45
pH	7.05	7.14	6.98
Sp. Cond. (mS/cm)	0.829	1.087	3.107

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	0.73	0.73	0.73
Duration (hrs.)	40	40	40
Intensity (in./hr.)	0.018	0.018	0.018
Discharge (cf.)	281,573	143,084	56,257

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

MAY 28-30, 2021

INTRODUCTION

Versar field staff traveled to the site on May 28 to deploy siphon samplers and program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 6:36 p.m. the evening of Friday, May 28. At the Wheel Creek Rain Gauge Station, 1.58 inches of rain was recorded for the duration of the storm.

On the morning of May 28, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the rising limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on May 30 to composite automated samples. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on May 30.

RESULTS

Hydrographs for the May 28-30 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the May 28-30 event are shown in Table A-5.

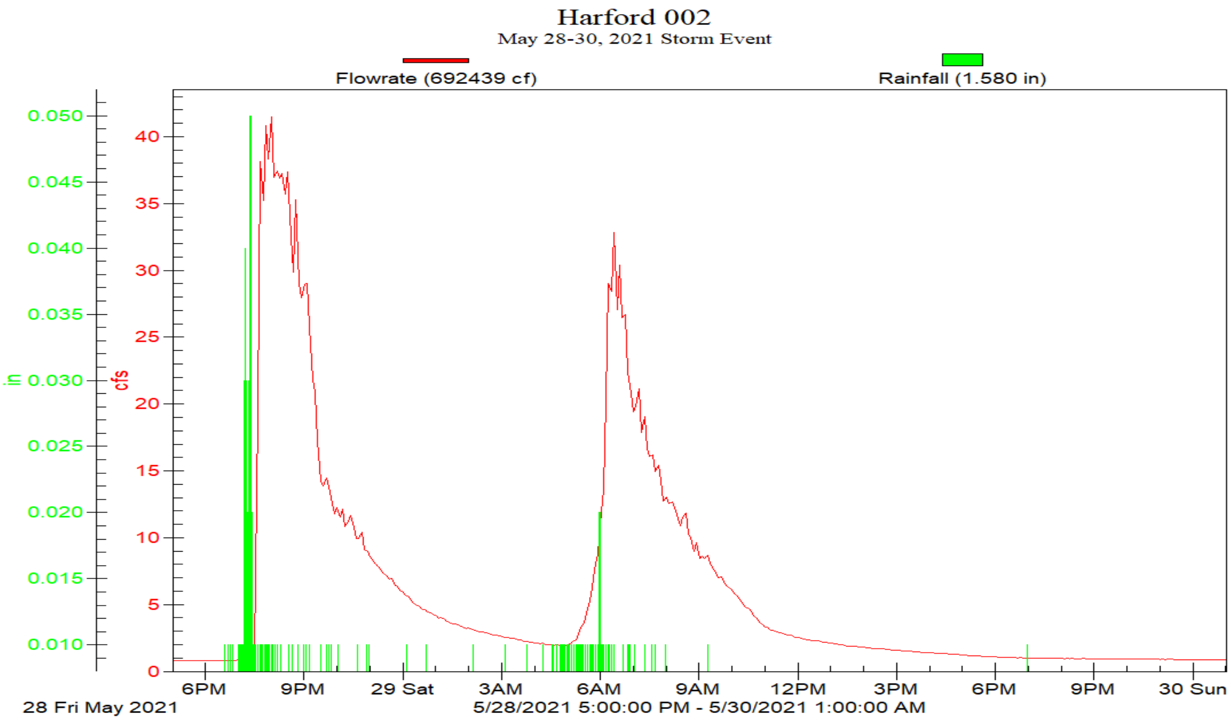

Figure A-1. Hydrograph at Station WC002 for May 28-30, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

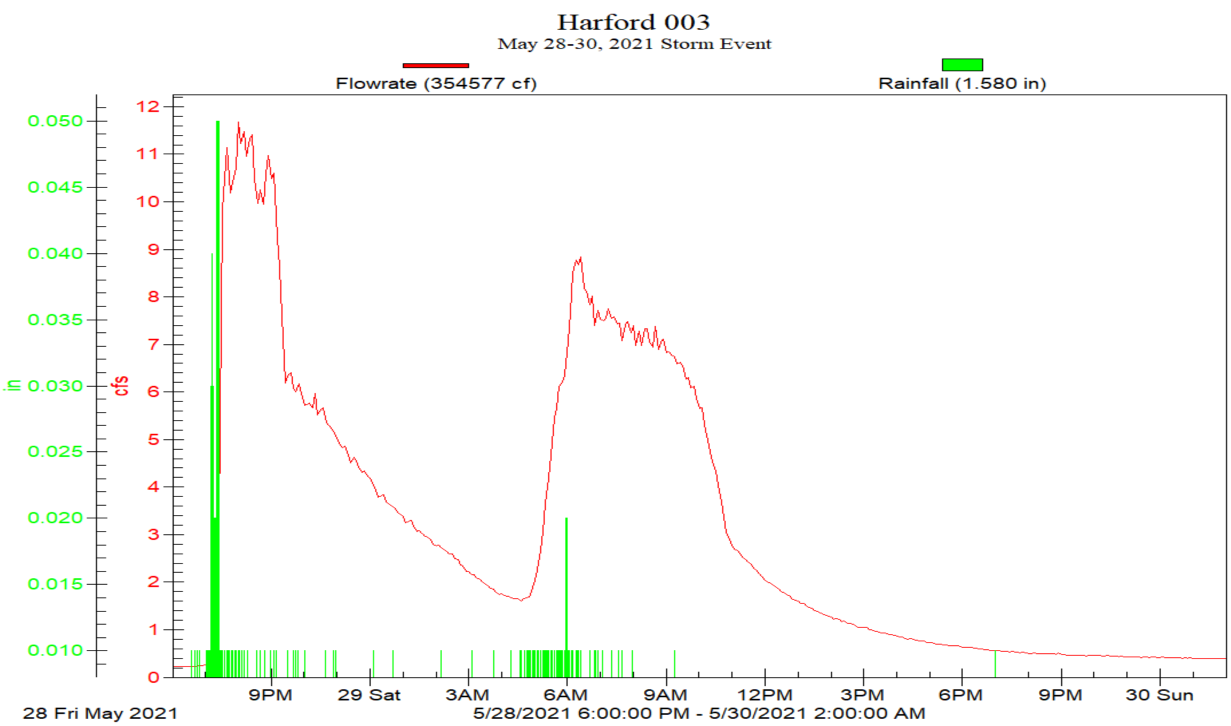

Figure A-2. Hydrograph at Station WC003 for May 28-30, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

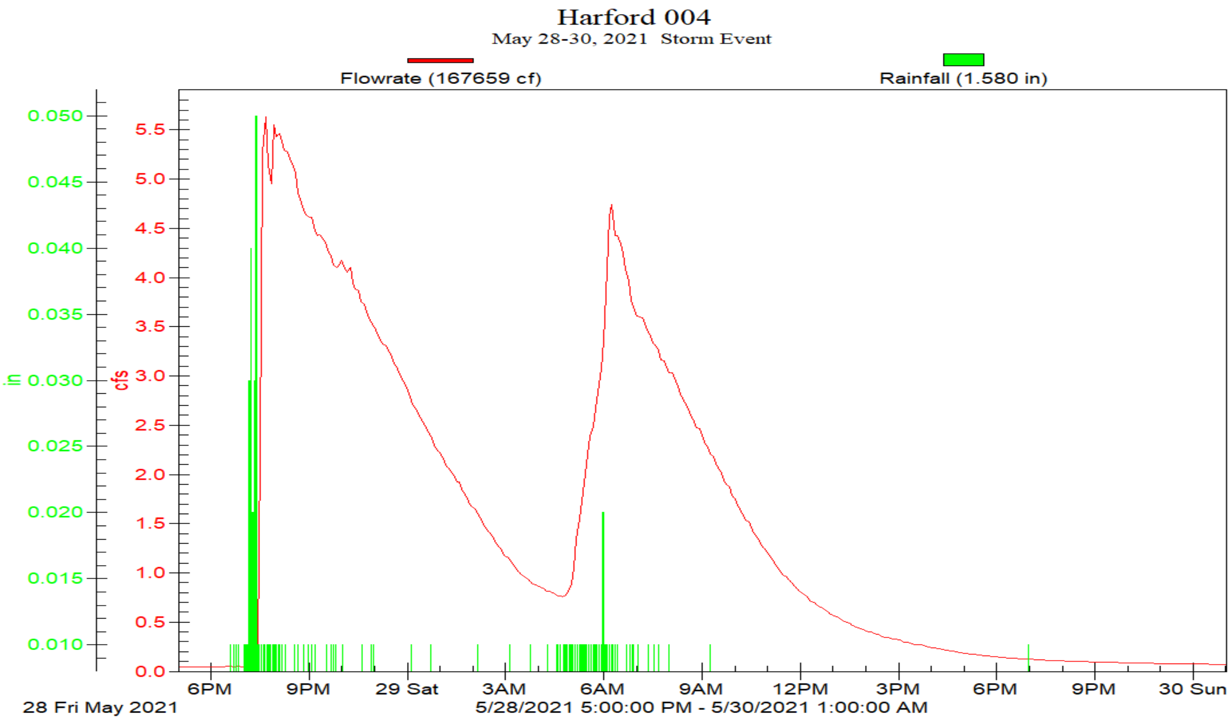

Figure A-3. Hydrograph at Station WC004 for May 28-30, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb			
Constituent	28-30-May-2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	4	2	3
Nitrate-Nitrite Nitrogen	0.9	0.8	1.5
Orthophosphate Phosphorus	<0.05	<0.05	0.01
Solids (Suspended)	5	17	30
Copper	0.005	0.009	0.010
Lead	<0.001	0.001	0.001
Zinc	0.012	0.023	0.037
Ammonia Nitrogen	0.22	<0.30	<0.30
Kjeldahl Nitrogen (Total)	4.2	1.0	1.1
Total Phosphorus	0.13	0.08	0.09
Hardness	128	120	196
Chloride	63.4	103	130
pH	7.53	7.51	7.51

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	28-30-May-2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	3	3	3
Nitrate-Nitrite Nitrogen	0.5	0.3	0.3
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	15	17	19
Copper	0.009	0.008	0.009
Lead	0.001	<0.001	0.001
Zinc	0.024	0.019	0.030
Ammonia Nitrogen	0.06	<0.30	<0.30
Kjeldahl Nitrogen (Total)	0.9	0.9	1.0
Total Phosphorus	0.07	0.04	0.06
Hardness	54.0	68.0	40.0
Chloride	66.2	138	149
pH	7.63	7.54	7.46

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	**28-30-May-2021**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	2	1	1
Nitrate-Nitrite Nitrogen	0.6	0.6	0.4
Orthophosphate Phosphorus	<0.05	0.01	0.01
Solids (Suspended)	5	<2	4
Copper	0.007	0.006	0.008
Lead	<0.001	<0.001	0.001
Zinc	0.011	0.008	0.025
Ammonia Nitrogen	<0.30	<0.30	<0.30
Kjeldahl Nitrogen (Total)	0.7	0.8	0.9
Total Phosphorus	0.05	0.04	0.04
Hardness	64.0	86.0	50.0
Chloride	60.7	93.9	105
pH	7.56	7.53	7.42

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
May 28, 2021 (Rising)			
TPH (mg/L)	<5.0	<5.0	<5.0
E. coli (MPN/100 ml)	147	201	649
Temp (C)	17	16.8	16.4
DO (mg/L)	8.59	8.65	6.14
pH	7.21	7.22	6.84
Sp. Cond. (mS/cm)	0.522	0.538	1.361

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	1.58	1.58	1.58
Duration (hrs.)	32	32	32
Intensity (in./hr.)	0.049	0.049	0.049
Discharge (cf.)	692,439	354,579	167,659

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APPENDIX B

RATING CURVES

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Table B-1. Station WC002 subset rating curve from data points collected in 2020-2021

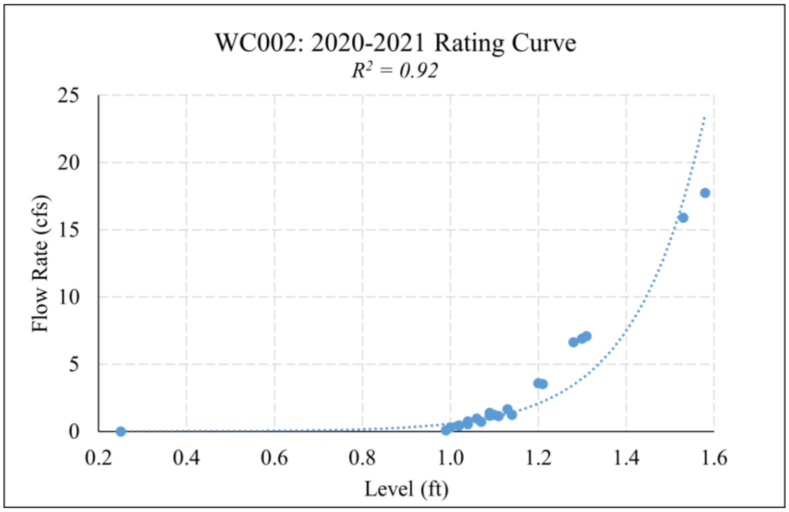
Level (ft)	Flow Rate (cfs)
0.25	0.010
0.99	0.091
1.00	0.295
1.02	0.422
1.04	0.764
1.07	0.727
1.09	1.189
1.11	1.146
1.13	1.646
1.21	3.531
1.28	6.631
1.30	6.906
1.53	15.892
1.58	17.736

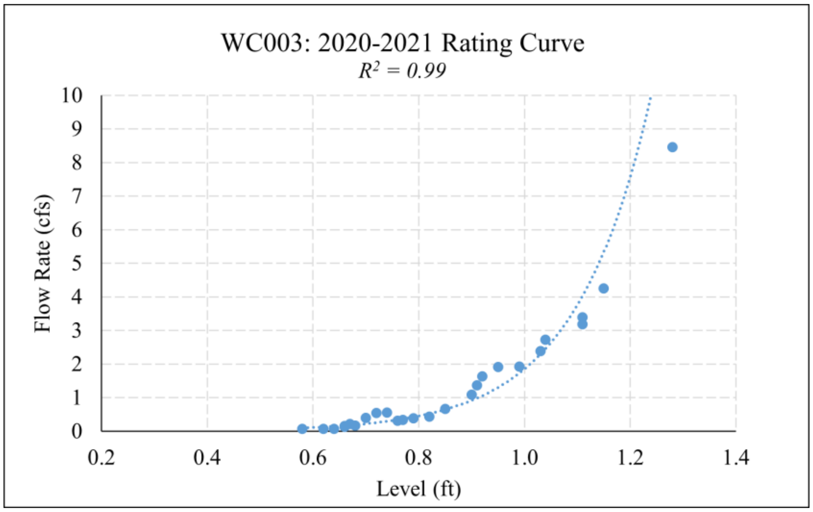
Table B-2. Station WC003 subset rating curve from data points collected in 2020-2021

Level (ft)	Flow Rate (cfs)
0.58	0.067
0.66	0.154
0.70	0.397
0.79	0.389
0.82	0.439
0.85	0.664
0.90	1.093
0.92	1.637
0.99	1.929
1.03	2.389
1.04	2.726
1.11	3.189
1.15	4.250
1.28	8.454

Table B-3. Station WC004 subset rating curve from data points collected in 2020-2021

Level (ft)	Flow Rate (cfs)
0.43	0.010
0.54	0.032
0.56	0.037
0.58	0.216
0.61	0.311
0.64	0.281
0.79	1.023
0.89	2.063
0.92	2.308
0.95	2.770
0.96	2.895
1.00	3.623
1.17	6.878
1.20	7.914





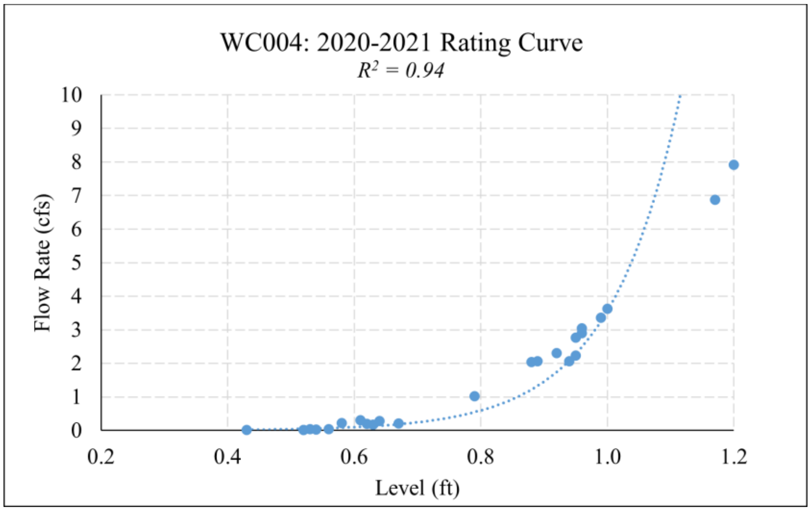


Figure B-1. Rating Curves for Stations WC002, WC003, and WC004

APPENDIX C

RAINFALL TOTALS

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Table C-1. July 2020 – June 2021 rainfall data from USGS Atkisson logger (inches)

Day	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
1	0.01	0	0	0.04	0.37	0	1.07	---	0.19	0.17	0	0
2	0	0	0.38	0.15	0	0	0.03	---	0	0	0	0
3	0	0.17	0.20	0	0	0	0.25	---	0	0	0.32	2.62
4	0	3.67	0	0	0	0.37	0	0	0	0	0.02	---
5	0.08	0	0	0.03	0	0.62	0	0.09	0	0	0.27	---
6	0.12	0.20	0	0	0	0	0	0	0	0	0	---
7	0.03	1.59	0	0	0	0	0	0.50	0	0	0.20	0
8	0	0.01	0	0	0	0	0	0	0	0	0.15	0.38
9	0	0	0.08	0	0	0	---	0	0	0.13	0	0.08
10	0.43	0	0.12	0	0	0	---	0	0	0.01	0	0.14
11	0.03	0	0	0.30	1.25	0	---	0	0	1.05	0	1.04
12	0.01	0.07	0.02	0.66	0.96	0	---	0	0	0.07	0	0.01
13	0.01	0.30	0	0.10	0.03	0	---	0	0	0	0	0
14	0	0	0	0	0	1.06	---	0	0	0.08	0	0.03
15	0	0.05	0	0	0.02	0	---	0.72	0	0	0	0.05
16	0	0.52	0	0.14	0	1.28	---	0.58	0	0	0	0
17	0.01	0.15	0	0	0	0	---	0	0	0	0	0
18	0	0	0	0	0	0	---	0	0.82	0	0	0
19	0.01	0.11	0	0	0	0	---	---	0.01	0	0	0
20	0	0	0	0	0	0	---	---	0	0	0	0
21	0	0	0	0.01	0	0.01	---	0	0	0	0	0.51
22	1.13	0.02	0	0	0	0.01	---	0.84	0	0	0	0.47
23	0	0.74	0	0	0.12	0	---	0	0	0	0	0
24	1.83	0.27	0	0	0	1.02	---	0	2.12	0.13	0	0
25	0.01	0	0	0.06	0	0.40	---	0	0	0.29	0	0
26	0	0	1.31	0.03	0.22	0	---	0.16	0.01	0	0.21	0
27	0	0	0.02	0	0	0	---	0.42	0	0	0	0
28	0	0.09	0	0	0	0	0	0.86	0.82	0	0.98	0
29	0	0.82	1.74	2.07	0	0	0		0	0.21	0.75	0
30	0.12	0.01	0.27	0.16	2.97	0	0		0	0	0.26	0.02
31	0.33	0.05		0		0.01	0		0.50		0	
Total Rain	**4.16**	**8.84**	**4.14**	**3.75**	**5.94**	**4.78**	**1.35**	**4.17**	**4.47**	**2.14**	**3.16**	**5.35**
											Annual Rainfall Total:	**52.25**

"---" = gauge offline

Table C-2. July 2020 – June 2021 rainfall data from Wheel Creek HOBO logger (inches)												
Day	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
1	0.00	0.00	0.01	0.03	0.34	0.00	1.04	0.00	0.17	0.14	0.00	0.00
2	0.00	0.00	0.34	0.15	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
3	0.00	0.17	0.19	0.00	0.00	0.00	0.23	0.15	0.00	0.00	0.31	1.79
4	0.00	3.72	0.01	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.02	0.00
5	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.08	0.00	0.00	0.25	0.00
6	0.17	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.01	1.35	0.00	0.00	0.00	0.01	0.00	0.45	0.00	0.00	0.20	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00
9	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00
10	0.41	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
11	0.03	0.00	0.00	0.43	1.25	0.00	0.00	0.00	0.00	0.96	0.00	0.00
12	0.01	0.01	0.02	0.57	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.02	0.23	0.00	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.98	0.00	0.08	0.00	0.08	0.00	0.00
15	0.00	0.10	0.00	0.00	0.00	0.00	0.34	0.54	0.00	0.00	0.00	0.00
16	0.00	0.46	0.00	0.13	0.00	0.70	0.02	0.40	0.00	0.00	0.00	0.00
17	0.00	0.16	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.72	0.00	0.00	0.00
19	0.00	0.10	0.00	0.00	0.00	0.06	0.00	0.01	0.01	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.38	0.00	0.00	0.00	0.52
22	1.00	0.02	0.00	0.00	0.00	0.01	0.00	0.10	0.00	0.00	0.00	0.44
23	0.00	0.85	0.00	0.00	0.09	0.00	0.00	0.58	0.00	0.00	0.00	0.00
24	1.43	0.30	0.00	0.00	0.00	1.03	0.00	0.00	1.99	0.22	0.00	0.00
25	0.01	0.01	0.00	0.10	0.01	0.40	0.00	0.00	0.01	0.16	0.00	0.00
26	0.00	0.00	1.23	0.02	0.00	0.01	0.12	0.13	0.01	0.00	0.19	0.00
27	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.39	0.00	0.00	0.00	0.00
28	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.81	0.72	0.00	0.93	0.00
29	0.00	0.79	1.35	1.89	0.00	0.00	0.00		0.00	0.19	0.65	0.00
30	0.13	0.01	0.13	0.16	0.00	0.00	0.00		0.00	0.00	0.19	0.03
31	0.32	0.04		0.00		0.00	0.00		0.45		0.00	
Total Rain	**3.54**	**8.62**	**3.79**	**3.59**	**2.63**	**3.63**	**1.77**	**4.37**	**4.08**	**1.92**	**2.87**	**2.78**
Annual Rainfall Total:												**43.59**

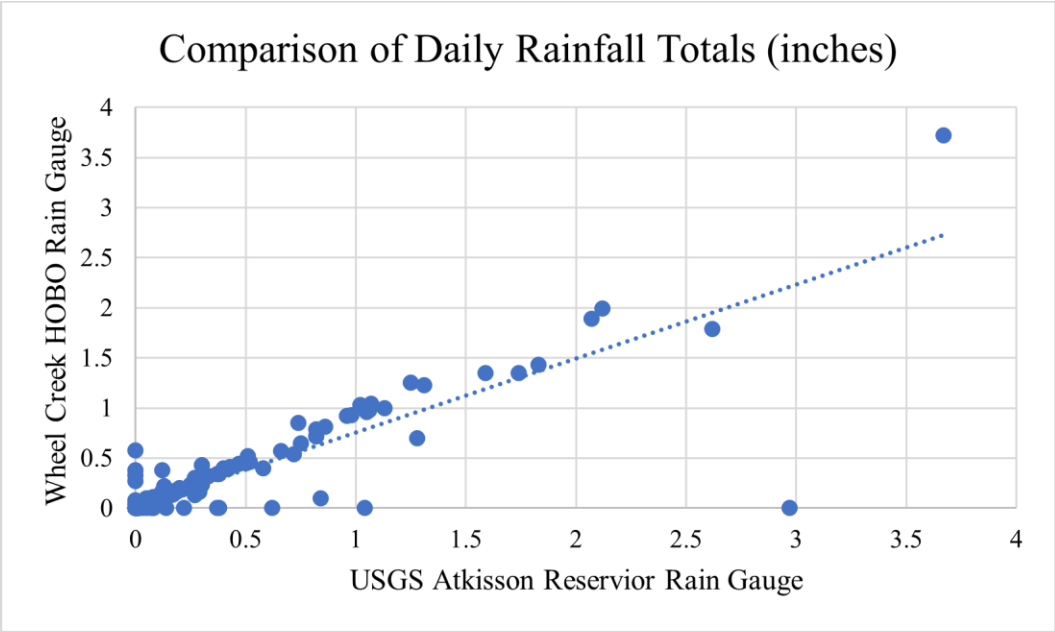

Figure C-1. Comparison of Daily Rainfall Totals for the USGS and Wheel Creek gauges

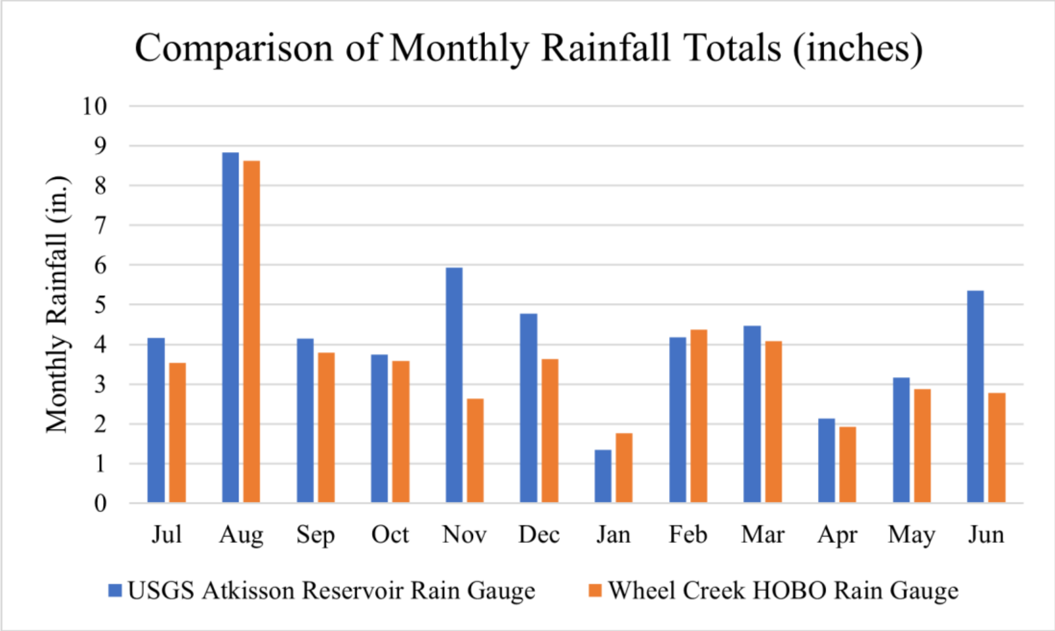

Figure C-2. Comparison of Monthly Rainfall Totals for the USGS and Wheel Creek gauges.

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APPENDIX D

TOTAL ANNUAL LOADS AND YIELDS OF POLLUTANTS AT WHEEL CREEK STUDY STATIONS

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Table D-1. Baseflow and storm flow MCs and EMCs, total annual loads, and annual yields (July 2020-June 2021)

Analyte	Station	Storm EMC (mg/L)	Baseflow MC (mg/L)	Annual Storm Load (lbs)	Annual Baseflow Load (lbs)	Annual Total Load (lbs)	Yield (lbs/ac/yr)
Ammonia	WC002	0.115	0.202	179.037	249.145	428.182	1.277
	WC003	0.097	0.085	74.939	26.805	101.744	0.874
	WC004	0.080	0.028	25.245	2.510	27.755	0.712
BOD	WC002	3.094	1.250	4,828.175	1,544.287	6,372.463	19.005
	WC003	2.589	1.083	2,010.344	341.629	2,351.973	20.206
	WC004	2.351	1.083	743.090	95.978	839.068	21.515
Chloride	WC002	118.480	143.833	184,884.918	177,695.998	362,580.916	1,081.363
	WC003	172.876	165.500	134,221.891	52,190.349	186,412.240	1,601.480
	WC004	197.050	324.750	62,279.092	28,771.253	91,050.345	2,334.624
Nitrate + Nitrite	WC002	0.564	1.517	880.082	1,873.735	2,753.818	8.213
	WC003	0.417	1.125	323.950	354.768	678.718	5.831
	WC004	0.359	2.508	113.426	222.226	335.652	8.606
TKN	WC002	1.034	0.508	1,614.114	628.010	2,242.124	6.687
	WC003	0.855	0.458	664.100	144.535	808.635	6.947
	WC004	0.715	0.383	226.114	33.961	260.075	6.669
Total P	WC002	0.127	0.039	198.661	48.388	247.049	0.737
	WC003	0.115	0.029	89.379	9.198	98.577	0.847
	WC004	0.077	0.028	24.364	2.436	26.801	0.687
Ortho-phosphate	WC002	0.048	0.046	75.007	56.624	131.631	0.393
	WC003	0.036	0.042	27.750	13.402	41.152	0.354
	WC004	0.037	0.042	11.666	3.765	15.431	0.396
TSS	WC002	23.638	5.333	36,886.596	6,588.959	43,475.555	129.662
	WC003	32.553	3.500	25,274.361	1,103.723	26,378.084	226.616
	WC004	16.676	2.500	5,270.689	221.488	5,492.176	140.825
Copper	WC002	6.763	1.283	10.554	1.585	12.140	0.036
	WC003	7.540	0.367	5.854	0.116	5.970	0.051
	WC004	5.969	0.867	1.887	0.077	1.963	0.050
Lead	WC002	1.452	0.444	2.266	0.549	2.814	0.008
	WC003	1.757	0.719	1.364	0.227	1.591	0.014
	WC004	1.313	0.648	0.415	0.057	0.472	0.012
Zinc	WC002	26.052	11.167	40.654	13.796	54.449	0.162
	WC003	31.419	9.750	24.394	3.075	27.468	0.236
	WC004	30.598	19.333	9.671	1.713	11.383	0.292

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APPENDIX E

TOTAL SEASONAL LOADS OF POLLUTANTS AT WHEEL CREEK STUDY STATIONS

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Table E-1. Baseflow and storm flow MCs and EMCs and total seasonal load (July 2020-June 2021)

Sample Year	Season	Station	Storm EMC (mg/L)	Baseflow MC (mg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
Ammonia							
2020	Summer	WC002	0.039	0.213	17.599	44.440	62.039
		WC003	0.141	0.057	31.427	2.210	33.638
		WC004	0.034	0.023	3.408	0.385	3.793
	Fall	WC002	0.140	0.190	75.869	71.631	147.500
		WC003	0.082	0.093	20.785	6.419	27.203
		WC004	0.093	0.033	8.426	0.716	9.142
2021	Winter	WC002	0.157	0.260	50.597	84.529	135.125
		WC003	0.115	0.080	17.525	5.384	22.909
		WC004	0.153	0.020	9.229	0.460	9.688
	Spring	WC002	0.132	0.143	32.150	46.584	78.734
		WC003	-	0.110	-	15.430	15.430
		WC004	-	0.037	-	1.013	1.013
BOD							
2020	Summer	WC002	2.665	1.667	1,202.549	347.187	1,549.736
		WC003	2.292	1.333	511.889	52.009	563.899
		WC004	2.009	1.333	202.792	22.023	224.815
	Fall	WC002	2.930	1.000	1,593.125	377.003	1,970.128
		WC003	2.340	1.000	594.672	68.771	663.443
		WC004	1.628	1.000	147.401	21.469	168.870
2021	Winter	WC002	3.540	1.333	1,142.033	433.482	1,575.515
		WC003	3.261	1.000	495.621	67.300	562.922
		WC004	3.148	1.000	190.279	22.983	213.262
	Spring	WC002	3.390	1.000	822.987	325.003	1,147.990
		WC003	2.339	1.000	343.718	140.271	483.989
		WC004	2.886	1.000	185.180	27.626	212.806
Chloride							
2020	Summer	WC002	24.141	109.333	10,894.990	22,775.490	33,670.480
		WC003	21.366	125.333	4,770.874	4,888.882	9,659.755
		WC004	18.959	189.333	1,913.497	3,127.210	5,040.708
	Fall	WC002	21.033	110.333	11,436.840	41,595.981	53,032.821
		WC003	27.847	124.667	7,078.168	8,573.458	15,651.626
		WC004	19.237	214.667	1,741.360	4,608.729	6,350.089
2021	Winter	WC002	337.369	228.333	108,842.209	74,233.770	183,075.980
		WC003	496.387	259.667	75,443.317	17,475.679	92,918.996
		WC004	581.122	557.333	35,120.236	12,809.026	47,929.262
	Spring	WC002	64.273	127.333	15,604.978	41,383.744	56,988.722
		WC003	118.930	152.333	17,476.165	21,367.951	38,844.116
		WC004	140.713	337.667	9,030.040	9,328.444	18,358.484

Table E-1. (Continued)							
Sample Year	**Season**	**Station**	**Storm EMC (mg/L)**	**Baseflow MC (mg/L)**	**Seasonal Storm Load (lbs)**	**Seasonal Baseflow Load (lbs)**	**Seasonal Total Load (lbs)**
Nitrate + Nitrite							
2020	Summer	WC002	0.473	1.267	213.438	263.862	477.301
		WC003	0.324	0.967	72.449	37.707	110.156
		WC004	0.189	2.300	19.061	37.989	57.050
	Fall	WC002	0.428	1.533	232.938	578.071	811.009
		WC003	0.321	1.067	81.623	73.356	154.979
		WC004	0.294	2.533	26.618	54.389	81.007
2021	Winter	WC002	0.720	1.800	232.129	585.201	817.329
		WC003	0.554	1.267	84.265	85.247	169.512
		WC004	0.438	2.533	26.475	58.223	84.698
	Spring	WC002	0.706	1.467	171.466	476.671	648.137
		WC003	0.521	1.200	76.511	168.325	244.836
		WC004	0.670	2.667	43.008	73.670	116.678
Orthophosphate							
2020	Summer	WC002	0.030	0.050	13.317	10.416	23.733
		WC003	0.024	0.050	5.349	1.950	7.299
		WC004	0.039	0.047	3.886	0.771	4.657
	Fall	WC002	0.044	0.057	23.995	21.363	45.359
		WC003	0.028	0.057	6.990	3.897	10.887
		WC004	0.042	0.057	3.822	1.217	5.039
2021	Winter	WC002	0.070	0.040	22.453	13.004	35.458
		WC003	0.052	0.023	7.869	1.570	9.439
		WC004	0.031	0.017	1.854	0.383	2.237
	Spring	WC002	0.050	0.037	12.140	11.917	24.056
		WC003	0.044	0.040	6.425	5.611	12.036
		WC004	0.036	0.050	2.282	1.381	3.664
TKN							
2020	Summer	WC002	0.613	0.700	276.808	145.819	422.626
		WC003	0.789	0.467	176.081	18.203	194.284
		WC004	0.571	0.400	57.652	6.607	64.258
	Fall	WC002	0.795	0.333	432.456	125.668	558.123
		WC003	0.697	0.400	177.268	27.508	204.776
		WC004	0.599	0.300	54.263	6.441	60.703
2021	Winter	WC002	0.963	0.467	310.548	151.719	462.267
		WC003	1.048	0.400	159.317	26.920	186.237
		WC004	0.821	0.333	49.616	7.661	57.277
	Spring	WC002	2.498	0.533	606.527	173.335	779.862
		WC003	0.919	0.567	135.049	79.487	214.536
		WC004	1.025	0.500	65.756	13.813	79.569

Table E-1. (Continued)

Sample Year	Season	Station	Storm EMC (mg/L)	Baseflow MC (mg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
Total Phosphorous							
2020	Summer	WC002	0.101	0.057	45.517	11.804	57.322
		WC003	0.129	0.023	28.843	0.910	29.753
		WC004	0.058	0.040	5.825	0.661	6.486
	Fall	WC002	0.125	0.020	68.142	7.540	75.682
		WC003	0.081	0.020	20.524	1.375	21.899
		WC004	0.048	0.023	4.336	0.501	4.837
2021	Winter	WC002	0.171	0.057	55.071	18.423	73.494
		WC003	0.166	0.040	25.238	2.692	27.930
		WC004	0.130	0.030	7.869	0.689	8.559
	Spring	WC002	0.097	0.023	23.650	7.583	31.234
		WC003	0.054	0.033	7.919	4.676	12.595
		WC004	0.068	0.017	4.362	0.460	4.822
TSS							
2020	Summer	WC002	16.403	10.000	7,402.882	2,083.124	9,486.006
		WC003	29.016	7.333	6,479.277	286.052	6,765.328
		WC004	13.028	2.667	1,314.920	44.045	1,358.965
	Fall	WC002	20.547	4.333	11,172.301	1,633.679	12,805.980
		WC003	17.022	2.333	4,326.627	160.466	4,487.092
		WC004	8.333	2.000	754.288	42.938	797.226
2021	Winter	WC002	41.239	3.333	13,304.518	1,083.705	14,388.223
		WC003	60.573	2.000	9,206.229	134.601	9,340.830
		WC004	26.265	2.333	1,587.314	53.626	1,640.941
	Spring	WC002	9.089	3.667	2,206.747	1,191.678	3,398.426
		WC003	14.648	2.333	2,152.396	327.299	2,479.695
		WC004	21.483	3.000	1,378.641	82.879	1,461.520
Copper							
2020	Summer	WC002	6.691	0.600	3.020	0.125	3.145
		WC003	8.246	0.567	1.841	0.022	1.863
		WC004	5.521	1.267	0.557	0.021	0.578
	Fall	WC002	6.327	0.667	3.440	0.251	3.691
		WC003	5.416	0.267	1.377	0.018	1.395
		WC004	5.067	0.400	0.459	0.009	0.467
2021	Winter	WC002	7.236	0.767	2.335	0.249	2.584
		WC003	8.713	0.467	1.324	0.031	1.356
		WC004	5.681	1.133	0.343	0.026	0.369
	Spring	WC002	6.837	3.100	1.660	1.008	2.667
		WC003	8.034	0.167	1.181	0.023	1.204
		WC004	9.247	0.667	0.593	0.018	0.612

Table E-1. (Continued)

Sample Year	Season	Station	Storm EMC (µg/L)	Baseflow MC (µg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
Lead							
2020	Summer	WC002	1.000	0.120	0.451	0.025	0.476
		WC003	1.804	0.767	0.403	0.030	0.433
		WC004	1.520	0.433	0.153	0.007	0.161
	Fall	WC002	1.827	0.533	0.993	0.201	1.194
		WC003	1.732	0.690	0.440	0.047	0.488
		WC004	1.000	1.000	0.091	0.021	0.112
2021	Winter	WC002	1.755	0.390	0.566	0.127	0.693
		WC003	2.114	0.733	0.321	0.049	0.371
		WC004	1.576	0.733	0.095	0.017	0.112
	Spring	WC002	1.000	0.733	0.243	0.238	0.481
		WC003	1.000	0.687	0.147	0.096	0.243
		WC004	1.000	0.427	0.064	0.012	0.076
Zinc							
2020	Summer	WC002	15.543	9.667	7.015	2.014	9.028
		WC003	27.861	8.333	6.221	0.325	6.546
		WC004	19.664	16.333	1.985	0.270	2.254
	Fall	WC002	19.931	11.333	10.838	4.273	15.110
		WC003	21.043	9.333	5.349	0.642	5.991
		WC004	17.848	15.667	1.616	0.336	1.952
2021	Winter	WC002	47.305	15.000	15.262	4.877	20.138
		WC003	51.729	13.333	7.862	0.897	8.759
		WC004	53.660	24.333	3.243	0.559	3.802
	Spring	WC002	16.806	8.667	4.080	2.817	6.897
		WC003	18.664	8.000	2.743	1.122	3.865
		WC004	31.840	21.000	2.043	0.580	2.623

"-" = Not Detected

Wheel Creek

Year 13 – 2021 Biological and Physical Habitat Monitoring Results

November | 2021

Prepared For

Harford County

Watershed Protection and Restoration

Department of Public Works

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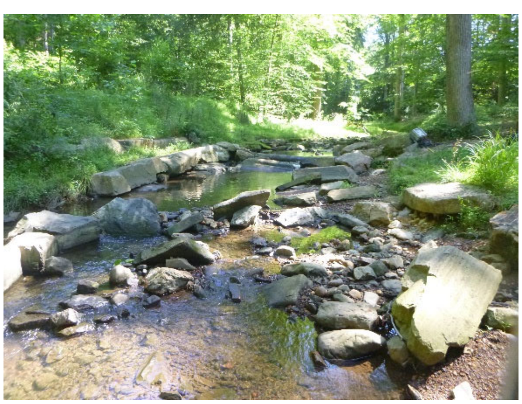
936 Ridgebrook Road

Sparks, MD 21152



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APPENDICES

1. Background

Harford County commissioned a Small Watershed Action Plan for a small subwatershed in the Bush River watershed. The Wheel Creek Small Watershed Action Plan (BayLand, 2008) was completed in August of 2008. Projects identified in the plan were submitted by the County for funding by the Chesapeake and Atlantic Coastal Bays Trust Fund (Trust Fund). Wheel Creek was one of the first project areas selected for funding for restoration by the Trust Fund. In 2009, the County began intensive monitoring of water quality, geomorphology, and ecological condition in the Wheel Creek watershed as projects were implemented. The first restoration project was completed during 2012, and the last projects were completed in July of 2017.

Wheel Creek is an unnamed tributary to Winters Run at Atkisson Reservoir, south of Bel Air, MD. It is a small subwatershed, approximately 393 acres in size (Becker, 2010). Land use in Wheel Creek watershed is dominated by urban development at 46.1% with forest at 34.7% and agriculture at 19.0%. Impervious surfaces in the watershed cover 21.4% of the watershed area. Harford County Public Schools owns the only parcel of substantial forest, on the Harford Glen property.

Maryland Department of Natural Resources' (MD DNR) Maryland Biological Stream Survey (MBSS) monitored seven sites in Wheel Creek and one additional local urban reference site as part of this effort. The MBSS was responsible for the collection and analysis of the data from 2009 to 2018. All sites were sampled through 2017. The four upstream most sites were discontinued prior to the 2018 sampling year. Sampling at the remaining three downstream Wheel Creek sites and the urban control site was continued by MD DNR through 2019.

KCI Technologies, Inc. completed the thirteenth year of chemical, physical, and biological stream sampling in spring and summer of 2021 at the four remaining stream sites in Wheel Creek. This technical memorandum describes the methods and results of the 2021 sampling effort conducted at those sites.

The primary goal of this effort is to characterize baseline stream conditions (biological, physical habitat, and *in situ* chemical) prior to additional restoration project/BMP implementation. A secondary goal is to conduct monitoring in Wheel Creel that can be used to document ecological uplift and habitat improvement as projects are completed within this watershed.

2. Methods

The monitoring effort includes chemical (*in situ* water quality), physical (habitat assessment), and biological (benthic macroinvertebrate, fish, herpetofauna, freshwater mussels, and crayfish) assessments conducted at each of the selected sites. The sampling methods used are consistent with MD DNR's MBSS. The methods have been developed locally and are calibrated specifically to Maryland's ecophysiographic regions and stream types.

2.1 Sampling Sites

Four sampling sites were selected within the Wheel Creek watershed (Figure 1) to characterize baseline stream conditions and to assess the effect of planned restoration on the ecological health of the watershed. A brief description of sites follows;

2.1.1 ATKI-101-X

The lowest downstream site in Wheel Creek is ATKI-101-X and it is located near the USGS gage on Wheel Creek. This site has been monitored continuously since 2009 by MBSS until 2019 and by KCI through 2021. The land use upstream of ATKI-101-X is mostly urban (46.1%) with the remaining portion in forest (34.7%) and agriculture (19.0%).

2.1.2 ATKI-102-X

ATKI-102-X is located on the furthest reach downstream, of the west branch of Wheel Creek, a short distance upstream of Wheel Road. The catchment upstream of this site is mostly urban (65.7%) with the remaining land classified as agriculture (18.6%) and forest (15.7%).

2.1.3 ATKI-003-X

ATKI-003-X is located on the furthest downstream site, of the east branch. Nearby, ATKI-102-X is a short distance upstream of Wheel Road. The upstream catchment to this site is mostly urban (57.5%) with the remaining land classified as forest (27.8%) and agriculture (14.1%).

2.1.4 LWIN-108-X

An urban control site is located nearby, on an unnamed tributary to Winters Run, downstream of the Atkinson Reservoir. This site was first sampled in 2009 and was continuously monitored by MBSS until 2019 and by KCI through 2021. The land use upstream of this site is mostly urban (50.5%) with the remaining portion in agriculture (26.1%) and forest (23.4%).

2.2 Water Quality

Water quality conditions were measured *in situ* during the summer 2021 sampling visits at all Wheel Creek sites. Currently, the MBSS does not measure *in situ* water quality at sites but did so in the past. *In situ* water quality methods used were consistent with those published in DNR, 2010. Field measured parameters include stream temperature, dissolved oxygen, pH, specific conductance, and turbidity. Measurements at each site were made at the upstream end of the 75-meter sampling reach. *In situ* measurements were made before any sampling activities started to avoid sampling water disturbed by other activities. Most *in situ* parameters (i.e., stream temperature, pH, specific conductivity, and dissolved oxygen) were measured using a multiparameter sonde (YSI Professional Plus), while turbidity was measured with a Hach 2100 Turbidimeter. Water quality meters are regularly inspected and maintained and were calibrated immediately prior to sampling to ensure proper usage and accuracy of the readings.

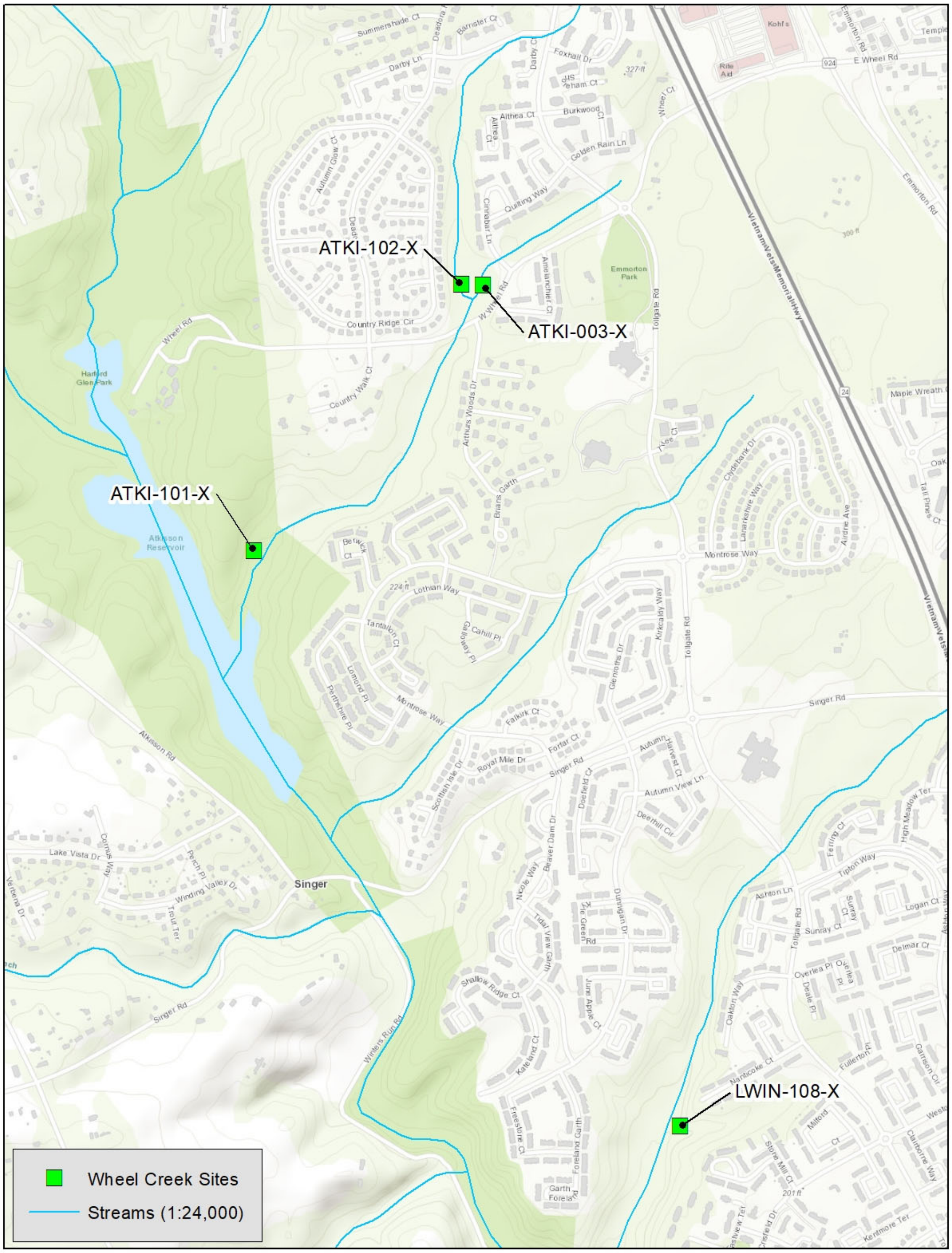

Figure 1 – Location of Sampling Sites

2.3 Physical Habitat Assessment

Each stream site was characterized based on visual observations of physical characteristics and various habitat parameters. The MBSS Physical Habitat Index (PHI; Paul et al. 2002) was used to assess the physical habitat at the site. The majority of the habitat parameters were collected during the summer visits, on June 24, and June 25, 2021.

To reduce individual sampler bias, assessments were completed as a team with discussion and agreement of the scoring for each parameter. In addition to the visual assessments, photographs were taken from three locations within each sampling reach (downstream end, midpoint, and upstream end) facing in the upstream and downstream direction, for a total of six (6) photographs per site.

The PHI incorporates the results of a series of habitat parameters selected for Coastal Plain, Piedmont and Highlands regions. While all parameters are rated during the field assessment, the Piedmont parameters were used to develop the PHI score for these sites because the Wheel Creek watershed is located in Maryland's Piedmont ecophysiographic region. In developing the PHI, MBSS identified eight parameters that have the most discriminatory power for the Piedmont streams. These parameters are used in calculating the PHI (Table 1). Several of the parameters have been found to be drainage area dependent and are scaled accordingly. The drainage area to each site was calculated in GIS by MBSS. The Year 13 analysis will utilize the same catchments for each site to remain consistent with MBSS.

Table 1 – PHI Piedmont Parameters

Piedmont Stream Parameters	
Instream Habitat	Epifaunal Substrate
Bank Stability	Percent Shading
Remoteness	Number Woody Debris/Root wads
Embeddedness	Riffle Quality

Each habitat parameter is given an assessment score ranging from 0-20, with the exception of shading (percentage 0-100%) and woody debris and root wads (total count). A prepared score and scaled score (0-100) are then calculated. The average of these scores yields the final PHI score. The final scores are then ranked according to the ranges shown in Table 2 and assigned corresponding narrative ratings, which allows for a score that can be compared to habitat assessments performed statewide.

Table 2 – PHI Score and Ratings

PHI Score	Narrative Rating
81.0 – 100.0	Minimally Degraded
66.0 – 80.9	Partially Degraded
51.0 – 65.9	Degraded
0.0 – 50.9	Severely Degraded

2.4 Benthic Macroinvertebrate Community Assessment

Benthic macroinvertebrate collection strictly followed MBSS procedures (Stranko et al. 2019). Sampling occurred during the Spring Index Period (March 1 – April 30), samples were collected from all four Wheel Creek sites on March 4, 2021. The monitoring sites consist of a 75-meter reach and benthic macroinvertebrate sampling is conducted once per year. The sampling methods utilize semi-quantitative field collections of the benthic macroinvertebrate community. The multi-habitat D-frame net approach is used to sample a range of the most productive habitat types present within the reach. Best available habitats include riffles, stable woody debris, root wads, root mats, leaf packs, aquatic macrophytes, and undercut banks. In this sampling approach, a total of twenty kicks or jabs (each approximately one square foot) are distributed proportionally among all best available habitats within the stream site and combined into a single composite sample and preserved in 95 percent ethanol. The composite sample contains material collected from approximately 20 square feet of habitat.

MBSS specifies that a minimum of 5% (1 in 20) of sites are selected for a duplicate sample (Stranko et al. 2019). Because the total number of samples in this project (4) is well below 20, Wheel Creek samples were pooled with other County monitoring project samples from Foster Branch (4) and Plumtree Run (5) to meet the field sampling QC objective (1 in 13, or 7.7%). The randomly selected QC site for 2021 was taken at Plum-1 associated with the Plumtree Run project.

2.4.1 Benthic Macroinvertebrate Sample Processing and Laboratory Identification

Benthic macroinvertebrate samples were processed and subsampled according to methods described in the MBSS Laboratory Methods for Benthic Macroinvertebrate Processing and Taxonomy (Boward and Friedman 2019). Subsampling was conducted to standardize the sample size and reduce variation caused by samples of different size. In this method, the sample was spread evenly across a numbered, gridded tray (100 total grids), and a grid was picked at random and picked clean of organisms. If the organism count was 100 or more, then the subsampling was complete. If the organism count was less than 100, then another grid was selected at random and picked clean of organisms. This repeated until the organism count reached 100 to 120 organisms. The 100 (plus 20 percent) organism target is used to allow for specimens that are missing parts or are not mature enough for proper identification, are terrestrial, or meiofauna. Identification of the subsampled specimens was conducted by Cole Ecological, Inc. Taxa were identified to the genus level for most organisms. Groups including Oligochaeta and Nematomorpha were identified to the family level while Nematoda was left at phylum. Individuals of early instars or those that were damaged were identified to the lowest possible level, which could be phylum or order, but in most cases was family. Chironomidae could be further subsampled depending on the number of individuals in the sample and the numbers in each subfamily or tribe. Most taxa were identified using a stereoscope. Temporary slide mounts viewed with a compound microscope were used to identify Oligochaeta to family and for Chironomid sorting to subfamily and tribe. Permanent slide mounts were then used for Chironomid genus level identification. Results were logged on a bench sheet and entered into a spreadsheet for analysis.

Benthic macroinvertebrate lab quality control procedures followed those used by the MBSS (Boward and Friedman 2019). Because the total number of samples in this project (4) is well below 20, Wheel Creek samples were pooled with samples from Foster Branch (4) and Plum Tree (5) to meet the laboratory QC objective (1 in 13, or 7.7%). The lab QC samples were selected at random from either Foster Branch, Plumtree Run, or Wheel Creek samples. One (1) sample was randomly selected for QC re-identification by an independent lab. Additionally, one sample from Wheel Creek, ATKI-003-X-2021, was selected as a laboratory duplicate to document QA/QC performance of laboratory sorting and identification procedures.

2.4.2 Benthic Macroinvertebrate Data Analysis

Benthic macroinvertebrate data were analyzed by KCI using methods developed by MBSS as outlined in the *New Biological Indicators to Better Assess the Condition of Maryland Streams* (Southerland et al. 2005). The Benthic Index of Biotic Integrity (BIBI) approach involves statistical analysis using metrics that have a predictable response to water quality and/or habitat impairment. The metrics selected fall into five major groups including taxa richness, composition measures, tolerance to perturbation, trophic classification, and habit measures. Raw values from each metric were given a score of 1, 3 or 5 based on ranges of values developed for each metric. The results were combined into a scaled IBI score from 1.00 to 5.00, and a corresponding narrative biological condition rating was applied.

Three sets of metric calculations have been developed for Maryland streams based on broad eco-physiographic regions. These include the Coastal Plain, Piedmont and combined Highlands. The study area is located in the Piedmont region; therefore, the following metrics (Table 3) and IBI scoring (Table 4) were used for the analysis.

Table 3 – Benthic Macroinvertebrate Metric Scoring for the Piedmont BIBI

Metric	Score		
	5	3	1
Total Number of Taxa	≥ 25	15 – 24	< 15
Number of EPT Taxa	≥ 11	5 – 10	< 5
Number of Ephemeroptera Taxa	≥ 4	2 – 3	< 2
% Intolerant to Urban	≥ 51	<51 – 12	< 12
% Chironomidae	≤ 24	>24 – 63	> 63
% Clingers	≥ 74	<74 – 31	< 31

Table 4 – BIBI Condition Ratings

IBI Score	Narrative Rating
4.00 – 5.00	Good
3.00 – 3.99	Fair
2.00 – 2.99	Poor
1.00 – 1.99	Very Poor

2.5 Fish Community Assessment

The fish community at each of the four Wheel Creek sites was sampled during the Summer Index Period, June 1 through September 30, according to methods described in *Maryland Biological Stream Survey: Round Four Field Sampling Manual* (Stranko et al. 2019). These data were collected at the four Wheel Creek sites on June 24, 2021 and June 25, 2021. In general, the approach uses two-pass electrofishing of the entire 75-meter study reach. Block nets were placed at the upstream and downstream ends of the reach, as well as at tributaries or outfall channels, to obstruct fish movement into or out of the study reach. Two passes were completed along the reach to ensure the segment was adequately sampled. The time in seconds for each pass was recorded and the level of effort for each pass was similar. Captured fish were identified to species and enumerated following MBSS protocols (Stranko et al. 2019). A total fish biomass for each electrofishing pass was measured. Unusual anomalies such as fin erosion, tumors, etc. were recorded. Photographic vouchers were taken in lieu of physical voucher specimens.

2.5.1 Fish Data Analysis

Fish data for Wheel Creek sites were analyzed using methods developed by MBSS as outlined in the *New Biological Indicators to Better Assess the Condition of Maryland Streams* (Southerland et al. 2005). The IBI approach involves statistical analysis using metrics that have a predictable response to water quality and/or habitat impairment. Raw values from each metric were assigned a score of 1, 3 or 5 based on ranges of values developed for each metric. The results were combined into a scaled FIBI score, ranging from 1.00 to 5.00, and a corresponding narrative rating of 'Good', 'Fair', 'Poor' or 'Very Poor' was applied, again in accordance with standard practice.

Four sets of FIBI metric calculations have been developed for Maryland streams. These include the Coastal Plain, Eastern Piedmont, and warmwater and coldwater Highlands. Wheel Creek is located in the Eastern Piedmont region, therefore, the following metrics listed in Table 5 were used for the FIBI scoring (Table 6) and analysis.

Table 5 – Fish Metric Scoring for the Piedmont FIBI

Metric	Score		
	5	3	1
Abundance per Square Meter	≥ 1.25	<1.25 – 0.25	< 0.25
Number of Benthic species *	≥ 0.26	<0.26 – 0.09	< 0.09
% Tolerant	≤ 45	>45 – 68	> 68
% Generalist, Omnivores, Invertivores	≤ 80	>80 – 99.9	>99.9
Biomass per Square Meter	≥ 8.6	<8.6 – 4.0	< 4.0
% Lithophilic Spawners	≥ 61	<61 – 32	< 32

*Adjusted for catchment size

Table 6 – FIBI Condition Ratings

IBI Score	Narrative Rating
4.00 – 5.00	Good
3.00 – 3.99	Fair
2.00 – 2.99	Poor
1.00 – 1.99	Very Poor

2.6 Herpetofauna Survey

Herpetofauna (i.e., reptiles and amphibians) were surveyed at each of the four Wheel Creek sites using methods following MBSS protocols (Stranko et al. 2019). All collected individuals were identified to species level and released. Photographic vouchers were collected if a specimen could not be positively identified in the field.

Herpetofauna data collection occurs primarily to assist MBSS with supplementing their inventory of biodiversity in Maryland's streams. Currently, MBSS has not developed an index of biotic integrity for herpetofauna, and therefore, they were not used to evaluate the biological integrity of sampling sites throughout this study. Rather, the data are provided to help document existing conditions.

2.7 Freshwater Mussel Survey

A survey of freshwater mussels was conducted at each site using MBSS protocols (Stranko et al. 2019). A search for freshwater mussels was conducted at each site. Any live individuals encountered were identified, photographed, and then returned back to the stream as closely as possible to where they were collected. Any dead shells were retained as voucher specimens.

2.8 Crayfish Survey

Crayfish were surveyed for at each site using MBSS protocols (Stranko et al. 2019). All crayfish observed while electrofishing were captured and retained until the end of each electrofishing pass. Captured crayfish were identified to species and counted before release back into the stream, outside of the 75-meter sampling reach. Crayfish encountered outside of the electrofishing effort were identified and noted on the datasheet as an incidental observation. Any crayfish burrows observed in and around the sampling site were excavated and an attempt made to capture the burrowing crayfish.

2.9 Invasive Plant Survey

A survey of invasive plants was performed at each site during the Summer Index Period, following MBSS protocols (Stranko et al. 2019). The common name and relative abundance of invasive plants (i.e., present or extensive) within view of the study reach and within the 5-meter riparian vegetative zone parallel the stream channel were recorded.

Invasive plant data collection occurs to assist MBSS with supplementing their inventory of biodiversity. The data are provided to help document existing conditions at each site.

2.10 Quality Assurance and Quality Control

All work was conducted with strict adherence to established quality assurance and quality control procedures. Biological assessment methods have been designed to be consistent and comparable with the methods used by MBSS (Stranko et al. 2019). Field crews receive yearly training in MBSS protocols and certification by DNR to perform benthic macroinvertebrate and fish sampling procedures. All field forms are checked and signed by the Crew Leader before leaving the site. Digital data entry is also checked for accuracy. Field equipment are checked regularly and calibrated as necessary prior to use. Calculation of metric scores and IBIs are completed using KCI's controlled and verified spreadsheet and each site undergoes a documented quality control check.

3. Results

Biological monitoring and water quality sampling were conducted to assess the conditions in the Wheel Creek watershed. Presented below are the summary results for each monitoring component.

3.1 Water Quality

Water quality measurements were collected during the Summer Index Period sampling visit at each of the four Wheel Creek sites. Table 7 presents the results of the *in situ* water quality measurements.

Table 7 – In Situ Water Quality Measurement Results for 2020 and 2021

Site	Season	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (Units)	Specific Conductance (µS/cm)	Turbidity (NTU)
ATKI-101-X	Summer 2020	19.3	10.01	7.88	452.2	1.82
ATKI-101-X	Summer 2021	16.6	7.87	7.42	468.3	2.55
ATKI-102-X	Summer 2020	19.0	7.88	7.65	480.9	2.38
ATKI-102-X	Summer 2021	16.0	8.68	6.88	525.4	2.77
ATKI-003-X	Summer 2020	23.5	8.31	8.11	502.1	4.35
ATKI-003-X	Summer 2021	18.9	8.93	7.41	525.9	4.10
LWIN-108-X	Summer 2020	19.1	10.51	7.51	394.0	2.58
LWIN-108-X	Summer 2021	17.0	8.46	7.79	419.9	3.52

Shaded cells indicate values exceeding either water quality criteria or published values

MDE has established acceptable water quality standards for each designated Stream Use Classification, which are listed in the *Code of Maryland Regulations (COMAR) 26.08.02.03-.03 - Water Quality*. Wheel Creek is covered in *COMAR* in Sub-Basin 02-13-07: Bush River Area as Use I-P waters. Specific designated uses for Use I-P streams include public water supply, growth and propagation of fish and aquatic life, water supply for industrial and agricultural use, water contact sports, fishing, and leisure activities involving direct water contact.

The acceptable criteria for Use I-P waters are as follows:

- pH - 6.5 to 8.5
- DO - may not be less than 5 mg/l at any time
- Turbidity - maximum of 150 Nephelometric Turbidity Units (NTU's) and maximum monthly average of 50 NTU
- Temperature - maximum of 90°F (32°C) or ambient temperature of the surface water, whichever is greater

In situ water quality measurements for temperature, dissolved oxygen, pH, and turbidity were within COMAR standards for Use I-P streams. Although MDE does not have a water quality standard for specific conductivity, Morgan and others (Morgan et al, 2007; Morgan et al, 2012) have reported critical values for specific conductance in Maryland streams, above which there is a potential for detrimental effects on the stream biological communities. For the benthic macroinvertebrate community that critical value is 247 µS/cm, and for the fish community it is 171 µS/cm. Each of the four Wheel Creek stream sites had specific conductivity values far exceeding the threshold for both benthic macroinvertebrate and fish community impairments for all water quality sampling events during both 2020 and 2021. Conductivity levels in this watershed are likely influenced by runoff from impervious surfaces (i.e., roads, sidewalks, parking lots, roof tops). Increased stream inorganic ion concentrations (i.e., conductivity) in urban systems typically results from paved surface de-icing, accumulations in storm-water management facilities (Casey et al. 2013), runoff over impervious surfaces, passage through pipes, and exposure to other infrastructure (Cushman 2006). While elevated conductivity may not directly affect stream biota, its constituents (e.g., chloride, metals, and nutrients) may be present at levels that can cause biological impairment.

3.2 Physical Habitat Assessment

The summary results of the PHI habitat assessments for 2020 and 2021 are presented in Table 8. All Wheel Creek sites are exhibiting compromised physical habitat, with PHI ratings ranging from 'Degraded' to 'Partially Degraded' categories. Two sites, ATKI-003-X and LWIN-108-X saw increases in the narrative ratings from 'Degraded' in 2020 to 'Partially Degraded' in 2021, which are primarily due to increased woody debris and improved embeddedness scores. Overall, the relatively low habitat scores observed throughout the watershed are likely due to urbanization effects on the stream channels. Complete physical habitat data for each site are included in Appendix A.

Table 8 – PHI Habitat Assessment Results for 2020 and 2021

Site	Season/Year	PHI Score	PHI Narrative Rating
ATKI-101-X	Summer 2020	68.5	Partially Degraded
ATKI-101-X	Summer 2021	68.9	Partially Degraded
ATKI-102-X	Summer 2020	64.1	Degraded
ATKI-102-X	Summer 2021	63.8	Degraded
ATKI-003-X	Summer 2020	53.1	Degraded
ATKI-003-X	Summer 2021	73.0	Partially Degraded
LWIN-108-X	Summer 2020	61.9	Degraded
LWIN-108-X	Summer 2021	73.6	Partially Degraded

3.3 Benthic Macroinvertebrate Community

The results of 2021 benthic macroinvertebrate community assessments are presented in Table 9. For 2021 benthic macroinvertebrate sampling, all Wheel Creek sites had biological condition ratings in the 'Poor' or 'Very Poor' categories, with LWIN-108-X receiving the lowest score of 1.33. BIBI scores ranged from 1.33 to 2.00. The individual metrics scored consistently low across all sites with none of the sites receiving a score of 5 for any metrics. Two metrics, Percent Intolerant to Urban and Number of Ephemeroptera Taxa, scored consistently low across all four sites with each site scoring the lowest possible '1' for these two metrics. Minor differences in the other four metrics (Total Number of Taxa, Number of EPT Taxa, Percent Clingers, and Percent Chironomidae) accounted for the variation in BIBI scores. These low BIBI scores are likely due to a combination of degraded instream habitat and poor water quality. All sites had measured specific conductivity values greater than the published impairment threshold of 247 µS/cm for benthic macroinvertebrates (Morgan et al., 2007). Complete benthic macroinvertebrate data for 2021 at each site are included in Appendix B.

For 2021 benthic macroinvertebrate sampling, all Wheel Creek sites had biological condition ratings in the 'Poor' or 'Very Poor' categories, with LWIN-108-X receiving the lowest score of 1.33. BIBI scores ranged from 1.33 to 2.00. The individual metrics scored consistently low across all sites with none of the site receiving a score of 5 for any metrics. Two metrics, Percent Intolerant to Urban and Number of

Ephemeroptera Taxa, scored consistently low across all four sites with each site scoring the lowest possible '1' for these two metrics. Minor differences in the other four metrics (Total Number of Taxa, Number of EPT Taxa, Percent Clingers, and Percent Chironomidae) accounted for the variation in BIBI scores. These low BIBI scores are likely due to a combination of degraded instream habitat and poor water quality. All sites had measured specific conductivity values greater than the published impairment threshold of 247 µS/cm for benthic macroinvertebrates (Morgan et al., 2007).

Table 9 – Benthic Index of Biotic Integrity (BIBI) Summary Data – 2021

Metric	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
Metric Values				
Total Number of Taxa	22	17	23	16
Number of EPT Taxa	5	3	3	3
Number of Ephemeroptera Taxa	0	0	0	0
% Intolerant to Urban	4.8	0.8	0.0	0.8
% Chironomidae	81.5	61.7	58.3	91.5
% Clingers	0.8	0.8	47.2	7.7
Metric Scores				
Total Number of Taxa	3	3	3	3
Number of EPT Taxa	3	1	1	1
Number of Ephemeroptera Taxa	1	1	1	1
% Intolerant to Urban	1	1	1	1
% Chironomidae	1	3	3	1
% Clingers	1	1	3	1
BIBI Score	***1.67***	***1.67***	***2.00***	***1.33***
Narrative Rating	***Very Poor***	***Very Poor***	***Poor***	***Very Poor***

A comparison of BIBI scores from 2009 to 2021 is presented in Table 10 and Figure 2. Three of the four Wheel Creek sites had BIBI scores that were lower in 2021 than in 2020, but on par with scores obtained previously in the 2018 or 2019 seasons (ATKI-101-X, ATKI-102-X, LWIN-108-X). Site ATKI-003-X received a slightly higher BIBI score in 2021 (2.00) and a corresponding 'Poor' rating, which was an improvement from 2018 – 2020 where conditions were consistently rated as 'Very Poor'. Site ATKI-003-X experienced the largest BIBI score difference (+0.33), scoring a 1.67 in 2018 and a 2.00 in 2021. Meanwhile, sites ATKI-101-X, ATKI-102-X, and LWIN-108-X saw no change in BIBI score compared to 2018.

Table 10 – BIBI Scores and Narrative Ratings from 2009 through 2021.

Site	Year	BIBI Score	Narrative Rating
ATKI-101-X	Spring 2009	2.67	Poor
ATKI-101-X	Spring 2010	3.00	Fair
ATKI-101-X	Spring 2011	2.33	Poor
ATKI-101-X	Spring 2012	1.33	Very Poor
ATKI-101-X	Spring 2013	2.00	Poor
ATKI-101-X	Spring 2014	1.00	Very Poor
ATKI-101-X	Spring 2015	2.67	Poor
ATKI-101-X	Spring 2016	2.67	Poor
ATKI-101-X	Spring 2017	1.33	Very Poor
ATKI-101-X	Spring 2018	1.67	Very Poor
ATKI-101-X	Spring 2019	1.67	Very Poor
ATKI-101-X	Spring 2020	2.00	Poor
ATKI-101-X	Spring 2021	1.67	Very Poor
ATKI-102-X	Spring 2009	2.00	Poor
ATKI-102-X	Spring 2010	1.67	Very Poor
ATKI-102-X	Spring 2011	1.33	Very Poor
ATKI-102-X	Spring 2012	1.67	Very Poor
ATKI-102-X	Spring 2013	1.67	Very Poor
ATKI-102-X	Spring 2014	2.00	Poor
ATKI-102-X	Spring 2015	2.00	Poor
ATKI-102-X	Spring 2016	2.67	Poor
ATKI-102-X	Spring 2017	1.67	Very Poor
ATKI-102-X	Spring 2018	1.67	Very Poor
ATKI-102-X	Spring 2019	1.00	Very Poor
ATKI-102-X	Spring 2020	2.00	Poor
ATKI-102-X	Spring 2021	1.67	Very Poor
ATKI-003-X	Spring 2009	2.00	Poor
ATKI-003-X	Spring 2010	1.67	Very Poor
ATKI-003-X	Spring 2011	1.33	Very Poor
ATKI-003-X	Spring 2012	2.67	Poor
ATKI-003-X	Spring 2013	2.00	Poor
ATKI-003-X	Spring 2014	1.33	Very Poor
ATKI-003-X	Spring 2015	2.33	Poor
ATKI-003-X	Spring 2016	1.33	Very Poor
ATKI-003-X	Spring 2017	1.33	Very Poor
ATKI-003-X	Spring 2018	1.67	Very Poor
ATKI-003-X	Spring 2019	1.33	Very Poor
ATKI-003-X	Spring 2020	1.67	Very Poor
ATKI-003-X	Spring 2021	2.00	Poor
LWIN-108-X	Spring 2009	2.67	Poor
LWIN-108-X	Spring 2010	3.00	Fair
LWIN-108-X	Spring 2011	1.33	Very Poor
LWIN-108-X	Spring 2012	3.00	Fair
LWIN-108-X	Spring 2013	2.67	Poor
LWIN-108-X	Spring 2014	1.67	Very Poor
LWIN-108-X	Spring 2015	2.33	Poor
LWIN-108-X	Spring 2016	3.00	Fair
LWIN-108-X	Spring 2017	2.00	Poor
LWIN-108-X	Spring 2018	1.33	Very Poor
LWIN-108-X	Spring 2019	1.33	Very Poor
LWIN-108-X	Spring 2020	1.67	Very Poor
LWIN-108-X	Spring 2021	1.33	Very Poor

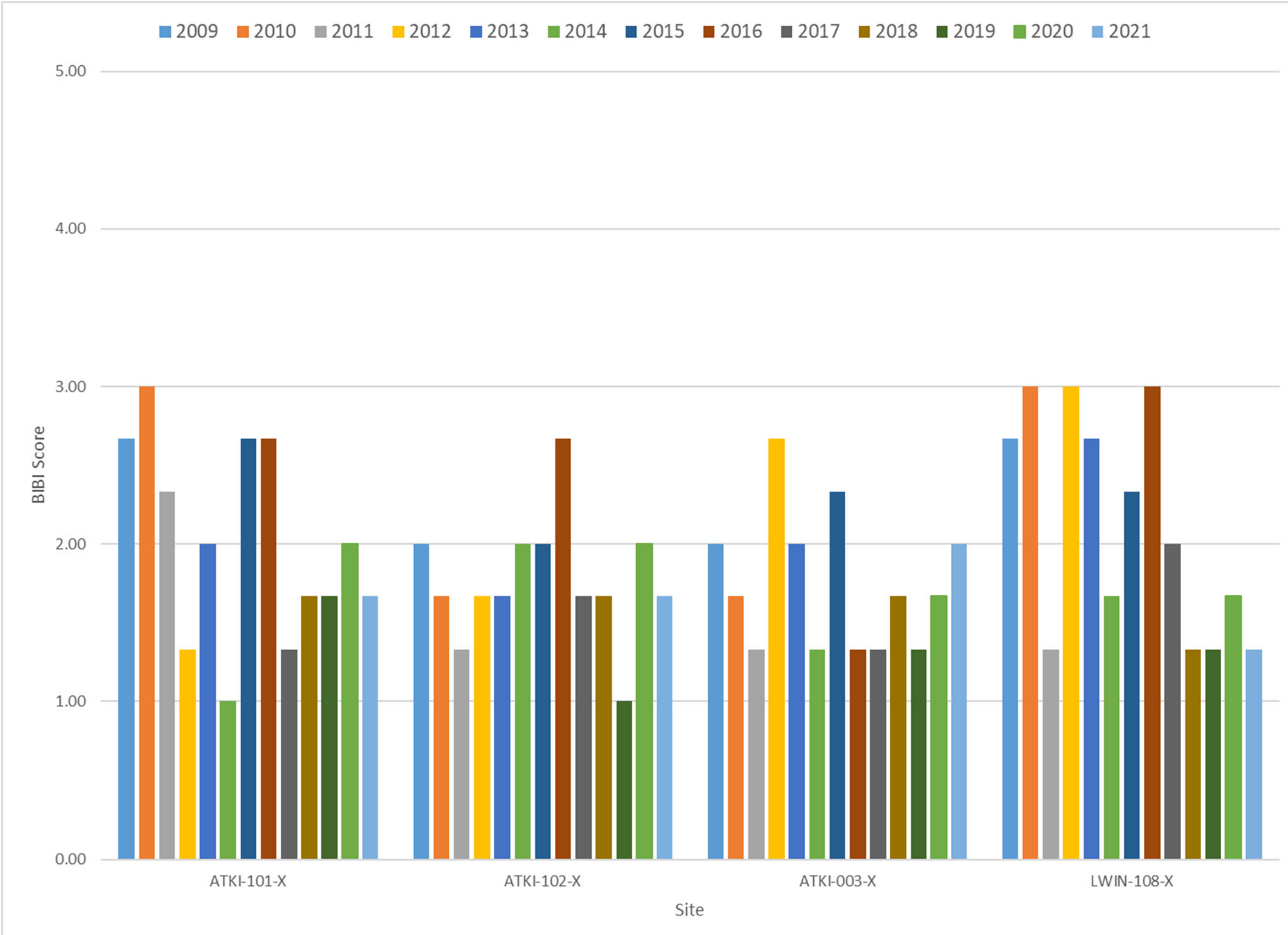

Figure 2 – Wheel Creek BIBI Scores by Year

3.4 Fish Community

The results of the 2021 fish community assessments are presented in Table 11 and a cumulative list of species collected at each site (2020 – 2021) can be found in Table 12. Complete fish community data from 2021 for each site are included in Appendix C.

Table 11 – Fish Index of Biotic Integrity (FIBI) Summary Data – 2021

Metric	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
Metric Values				
Abundance per Square Meter	3.53	6.44	2.45	1.03
Adjusted Number of Benthic Species	2.26	2.89	6.00	2.20
% Tolerant	42.7%	82.6%	92.1%	34.7%
% Generalist, Omnivores, Invertivores	64.5%	82.6%	92.3%	63.3%
Biomass per Square Meter	8.73	18.10	8.81	8.83
% Lithophilic Spawners	53.3%	40.7%	63.9%	73.7%
Metric Scores				
Abundance per Square Meter	5	5	5	3
Adjusted Number of Benthic Species	5	5	5	5
% Tolerant	5	1	1	5
% Generalist, Omnivores, Invertivores	5	3	3	5
Biomass per Square Meter	5	5	5	5
% Lithophilic Spawners	3	3	5	5
FIBI Score	**4.67**	**3.67**	**4.00**	**4.67**
Narrative Rating	**Good**	**Fair**	**Good**	**Good**

Table 12 – List of Fish Species Collected at Wheel Creek Sites – 2020 and 2021

Common Name	Scientific Name	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
White Sucker	*Catostomus commersonii*	X	X	X	X
Bluntnose Minnow	*Pimephales notatus*	X			X
Fathead Minnow	*Pimephales promelas*	X			
Common Shiner	*Luxilus cornutus*	X			X
Rosyside Dace	*Clinostomus funduloides*	X			X
Creek Chub	*Semotilus atromaculatus*	X	X	X	X
Fallfish	*Semotilus corporalis*	X			X
Blacknose Dace	*Rhinichthys atratulus*	X	X	X	X
Longnose Dace	*Rhinichthys cataractae*	X			X
Eastern Mosquitofish	*Gambusia holbrooki*	X			
Blue Ridge Sculpin	*Cottus caeruleomentum*	X	X	X	X
Tessellated Darter	*Etheostoma olmstedi*	X			
Redbreast Sunfish	*Lepomis auritus*	X			X
Bluegill	*Lepomis macrochirus*	X			
Pumpkinseed	*Lepomis gibbosus*	X			
Northern Hogsucker	*Hypentelium nigricans*				X
American Eel	*Anguilla rostrata*				X
Margined Madtom	*Noturus insignis*				X
Banded Killifish	*Fundulus diaphanus*	X			
Golden Shiner	*Notemigonus crysoleucas*	X			
Cutlip Minnow	*Exoglossum maxillingua*	X			
Goldfish	*Carassius auratus*			X	

The Wheel Creek sites had FIBI ratings ranging from ‘Fair’ to ‘Good’ in all monitoring years. Both sites LWIN-108-X and ATKI-101-X had the highest FIBI scores in 2021, 4.67 which rated ‘Good’. ATKI-102-X was rated as ‘Fair’ with a score of 3.67 and ATKI-003-X was rated as ‘Good’ with a score of 4.00. ATKI-101-X had the highest diversity of the four sites, with sixteen species of fish, followed by LWIN-108-X, with twelve species of fish. ATKI-003-X had five species and ATKI-102-X had four species captured in 2021. Metrics for Adjusted Number of Benthic Species was consistent between the four sites. Percent tolerant varied the most between the sites, with ATKI-101-X and LWIN-108-X scoring a ‘5’, and ATKI-102-X and ATKI-003-X scoring a ‘1’. Minor differences in the other three metrics between sites accounted for the minor variability in FIBI scores between sites.

A comparison of FIBI scores from 2009 to 2019 during the MBSS years of monitoring as well as 2020 and 2021, is presented in Table 10 and Figure 2. All four sites had FIBI scores that were the same as or higher in 2021 than in the previous six years of monitoring. Site ATKI-101-X had the largest FIBI score difference (+1.67), scoring a 3.00 in 2018 and a 4.67 in 2021. FIBI scores at sites ATKI-003-X and LWIN-108-X have increased over the past several years, with ATKI-003-X increasing from 2.33 in 2017 to 4.00 in 2021, and LWIN-108-X increasing from 4.00 in 2018 to 4.67 in 2021. ATKI-102-X had no change between the last five years.

Table 13 – FIBI Scores and Narrative Ratings from 2009 through 2021.

Site	Year	FIBI Score	Narrative Rating
ATKI-101-X	Summer 2009	4.67	Good
ATKI-101-X	Summer 2010	4.33	Good
ATKI-101-X	Summer 2011	4.33	Good
ATKI-101-X	Summer 2012	4.00	Good
ATKI-101-X	Summer 2013	4.67	Good
ATKI-101-X	Summer 2014	4.00	Good
ATKI-101-X	Summer 2015	3.33	Fair
ATKI-101-X	Summer 2016	4.33	Good
ATKI-101-X	Summer 2017	3.67	Fair
ATKI-101-X	Summer 2018	3.00	Fair
ATKI-101-X	Summer 2019	3.67	Fair
ATKI-101-X	Summer 2020	4.00	Good
ATKI-101-X	Summer 2021	4.67	Good
ATKI-102-X	Summer 2009	5.00	Good
ATKI-102-X	Summer 2010	4.67	Good
ATKI-102-X	Summer 2011	4.33	Good
ATKI-102-X	Summer 2012	4.67	Good
ATKI-102-X	Summer 2013	4.67	Good
ATKI-102-X	Summer 2014	4.00	Good
ATKI-102-X	Summer 2015	3.67	Fair
ATKI-102-X	Summer 2016	3.33	Fair
ATKI-102-X	Summer 2017	3.67	Fair
ATKI-102-X	Summer 2018	3.67	Fair
ATKI-102-X	Summer 2019	3.67	Fair
ATKI-102-X	Summer 2020	3.67	Fair
ATKI-102-X	Summer 2021	3.67	Fair
ATKI-003-X	Summer 2009	4.00	Good
ATKI-003-X	Summer 2010	3.67	Fair
ATKI-003-X	Summer 2011	3.67	Fair
ATKI-003-X	Summer 2012	3.00	Fair
ATKI-003-X	Summer 2013	3.67	Fair
ATKI-003-X	Summer 2014	3.00	Fair
ATKI-003-X	Summer 2015	2.67	Poor
ATKI-003-X	Summer 2016	3.67	Fair
ATKI-003-X	Summer 2017	2.33	Poor
ATKI-003-X	Summer 2018	3.33	Fair
ATKI-003-X	Summer 2019	3.33	Fair
ATKI-003-X	Summer 2020	3.67	Fair
ATKI-003-X	Summer 2021	4.00	Good
LWIN-108-X	Summer 2009	4.67	Good
LWIN-108-X	Summer 2010	4.33	Good
LWIN-108-X	Summer 2011	4.33	Good
LWIN-108-X	Summer 2012	4.33	Good
LWIN-108-X	Summer 2013	4.67	Good
LWIN-108-X	Summer 2014	4.33	Good
LWIN-108-X	Summer 2015	4.33	Good
LWIN-108-X	Summer 2016	4.33	Good
LWIN-108-X	Summer 2017	4.67	Good
LWIN-108-X	Summer 2018	4.00	Good
LWIN-108-X	Summer 2019	4.33	Good
LWIN-108-X	Summer 2020	4.33	Good
LWIN-108-X	Summer 2021	4.67	Good

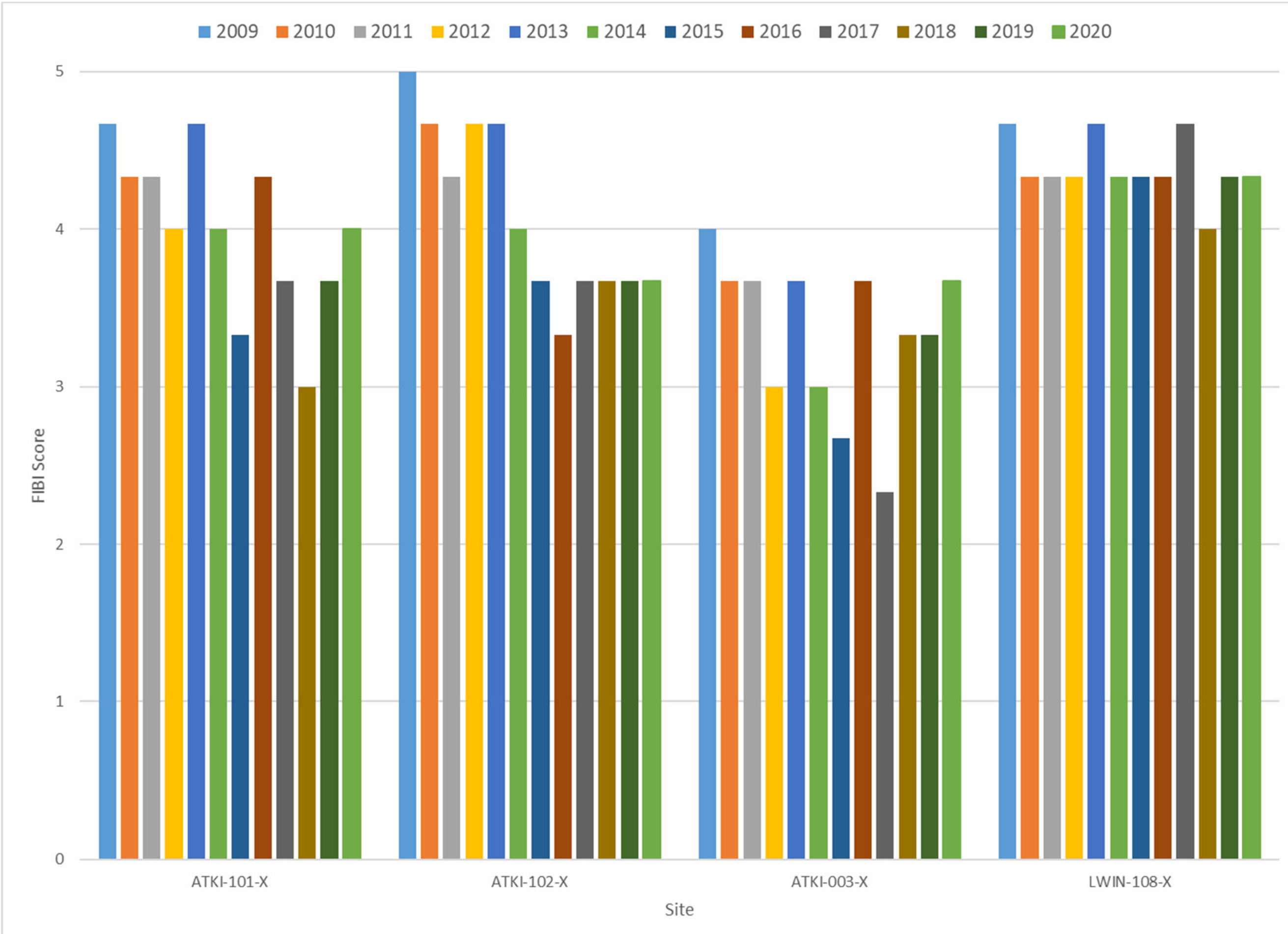

Figure 3 – Wheel Creek FIBI Scores by Year

3.5 Herpetofauna

At least three reptile or amphibian species were collected at each of the sites, as presented in Table 14, which presents all species found at each monitoring site across all sampling visits. ATKI-101-X had the highest diversity with six species found at the site. The most widely distributed species was Northern Green Frog, which was present at all four Wheel Creek sites. Numbers of stream salamander individuals were low at all sites where they were observed, and consisted entirely of the most pollution-tolerant species the Northern Two-lined Salamander.

Table 14 – Cumulative Herpetofauna Presence at Wheel Creek Sites

Common Name	Scientific Name	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
American Toad	*Anaxyrus americanus*	X			
Northern Green Frog	*Lithobates clamitans melanota*	X	X	X	X
Pickerel Frog	*Lithobates palustris*	X		X	X
American Bullfrog	*Lithobates catesbeianus*			X	
Cope's Gray Tree Frog	*Hyla chrysoscelis*		X		
Northern Watersnake	*Nerodia sipedon*	X	X		
Eastern Milk Snake	*Lampropeltis triangulum*			X	
Queen Snake	*Regina septemvittata*	X			X
Stream Salamanders					
Northern Two-lined Salamander	*Eurycea bislineata*	X	X		X

The low density and diversity of stream salamanders at all sites is likely due to a combination of habitat degradation and water quality impairment. There was very little suitable stream salamander habitat present at ATKI-102-X and ATKI-003-X during the first visit for the field crew to search. Stream salamanders generally prefer large cover objects over loose cobble and gravel, creating a moist microclimate and many interstices for shelter and foraging. Water quality may be influencing the distribution of stream salamanders in the Wheel Creek watershed. Measured specific conductivity was high at all four sites, ranging from 420 to 526 µS/cm. Stream salamanders breathe through their skins, and because of their highly permeable skin, are particularly sensitive to water quality impairments. The high conductivity values suggest that salamanders would experience osmotic difficulties in these conditions.

3.6 Freshwater Mussels

No freshwater mussels were observed at any Wheel Creek site during 2020 or 2021 field visits. The lack of freshwater mussels at these sites is likely due to a combination of habitat degradation and water quality impairment. Freshwater mussels are relatively sessile organisms which live partially embedded within the stream substrates. The flashy hydrology characteristic of urban streams like Wheel Creek create habitat conditions unsuitable for freshwater mussels. Also, it is likely that water quality conditions in urban streams are outside the range of tolerance of these sensitive organisms.

3.7 Crayfish

Crayfish were observed at all of the Wheel Creek sites, with the exception of LWIN-108-X in 2021. *Faxonius virilis*, a non-native species, was the only crayfish species observed. Crayfish burrows were not observed at any of the Wheel Creek sites. The lack of native crayfish is most likely due to competition with non-native crayfish. In the Patapsco River watershed, *Faxonius virilis* has displaced the native *Faxonius limosus* from the entire watershed (Kilian et al. 2010). It is likely that similar species displacement has occurred in the Winters Run watershed. Water quality conditions may also be impacting crayfish, but currently, the water quality requirements for crayfish in Maryland are poorly understood.

3.8 Invasive Plant Species

Invasive plant species were present at each of the four Wheel Creek sites. Table 15 presents all invasive species found at each monitoring site across all sampling visits. ATKI-102-X and ATKI-003-X both have seven invasive plant species, while ATKI-101-X has five species and LWIN-108-X only has two species. Mulitflora rose and Japanese stiltgrass were the most widely distributed invasive plant species, found at each of the four sites.

Table 15 – Cumulative Invasive Plant Species Presence at Wheel Creek Sites

Common Name	Scientific Name	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
Japanese barberry	*Berberis thunbergii*	X	X	X	
Oriental bittersweet	*Celastrus orbiculatus*	X	X	X	
Japanese stiltgrass	*Microstegium vimineum*	X	X	X	X
Multiflora rose	*Rosa multiflora*	X	X	X	X
Wineberry	*Rubus phoenicolasius*	X			
Mile-a-minute	*Persicaria perfoilata*		X	X	
Privet	*Ligustrum sp.*		X	X	
Japanese honeysuckle	*Lonicera japonica*		X	X	

4. Conclusions

Ecological conditions at the three treatment sites in Wheel Creek, as well as the urban control site, vary over time throughout the 13 years of monitoring, with some exhibiting trends towards further degradation. BIBI scores at all four sites have remained in the 'Very Poor' or 'Poor' categories, varying slightly from year to year. While two sites appear to show trends toward lower BIBI scores over time (Figure 4), Kendall correlations of BIBI versus year were only statistically significant at the 95% confidence interval for the urban control site, LWIN-108-X (correlation coeff.= -0.672, p = 0.003). FIBI scores at the three Wheel Creek treatment sites also vary over time, but generally remain in the 'Fair' category. Of the two sites showing trends toward lower FIBI scores over time (Figure 5), Kendall correlations of FIBI versus year were only statistically significant for one site, ATKI-102-X (correlation coeff.= -0.456, p = 0.045). Comparing data between the pre- and post-restoration periods, there is no discernable ecological lift in the IBI scores. The ecological condition of Wheel Creek, especially the benthic macroinvertebrate community, continues in a degraded condition similar to other post-restoration urban streams in central Maryland (Hilderbrand et al 2019; Southerland et al 2018). However, the urban control site is showing a trend towards further degradation of the benthic macroinvertebrate community in recent years, suggesting that recent restoration efforts may be ameliorating effects of urbanization within the watershed. Although, it should be noted that fish communities at the urban control site have consistently been rated as 'Good' throughout the entire monitoring period, and no impairment has been observed in recent years.

A more comprehensive analysis of data collected at Wheel Creek project sites will occur at the end of 2024. This larger analysis will integrate all ecological, habitat, and water quality data to try to identify correlations in the data set that would help understand what is affecting ecological condition in the Wheel Creek watershed. Analysis will focus not only on the IBI scores, but on individual metrics and species-level response over time to try and highlight changes, if any exist, in the post-restoration data.

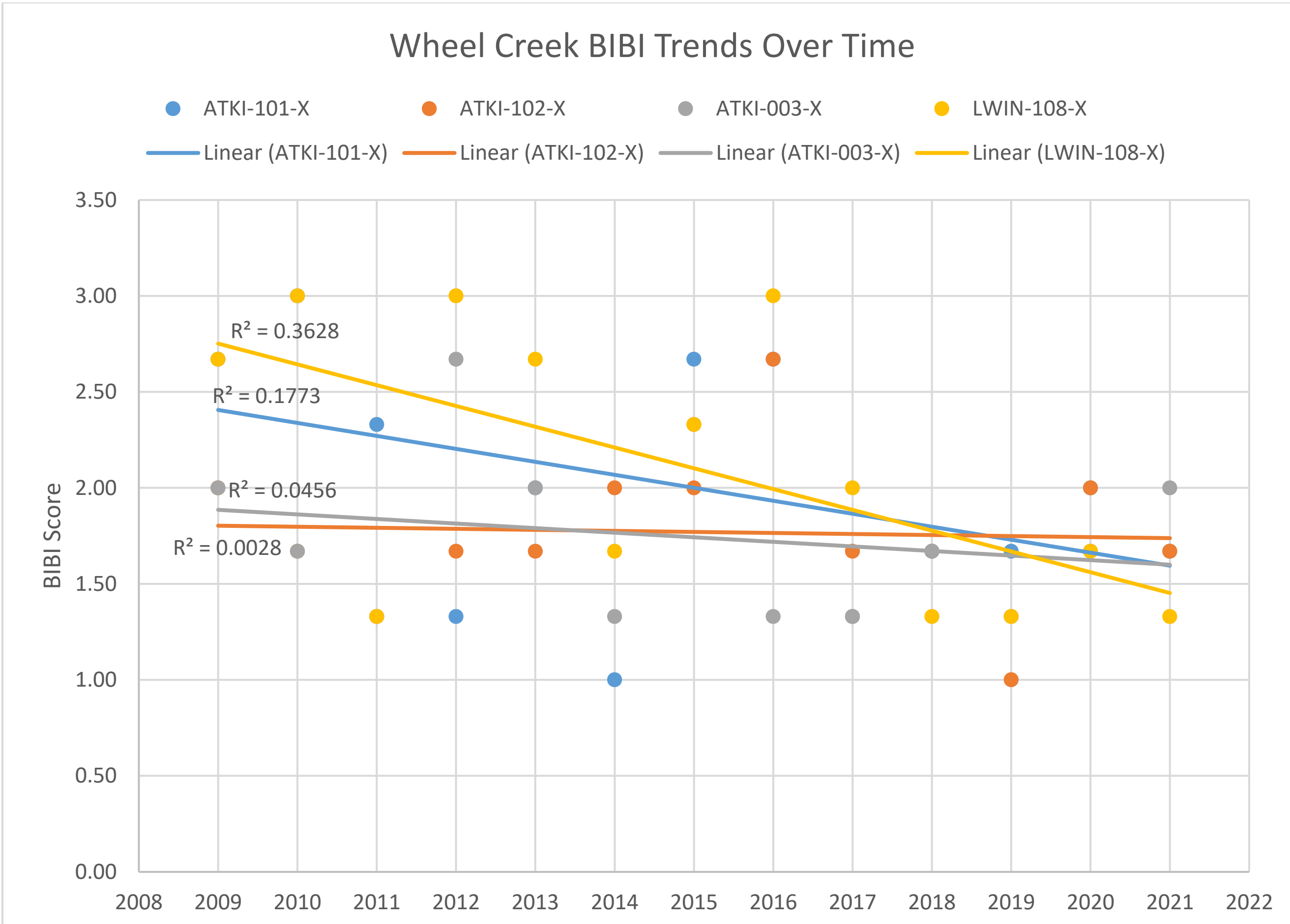

Figure 4 - BIBI Trends over time (2009 - 2021)

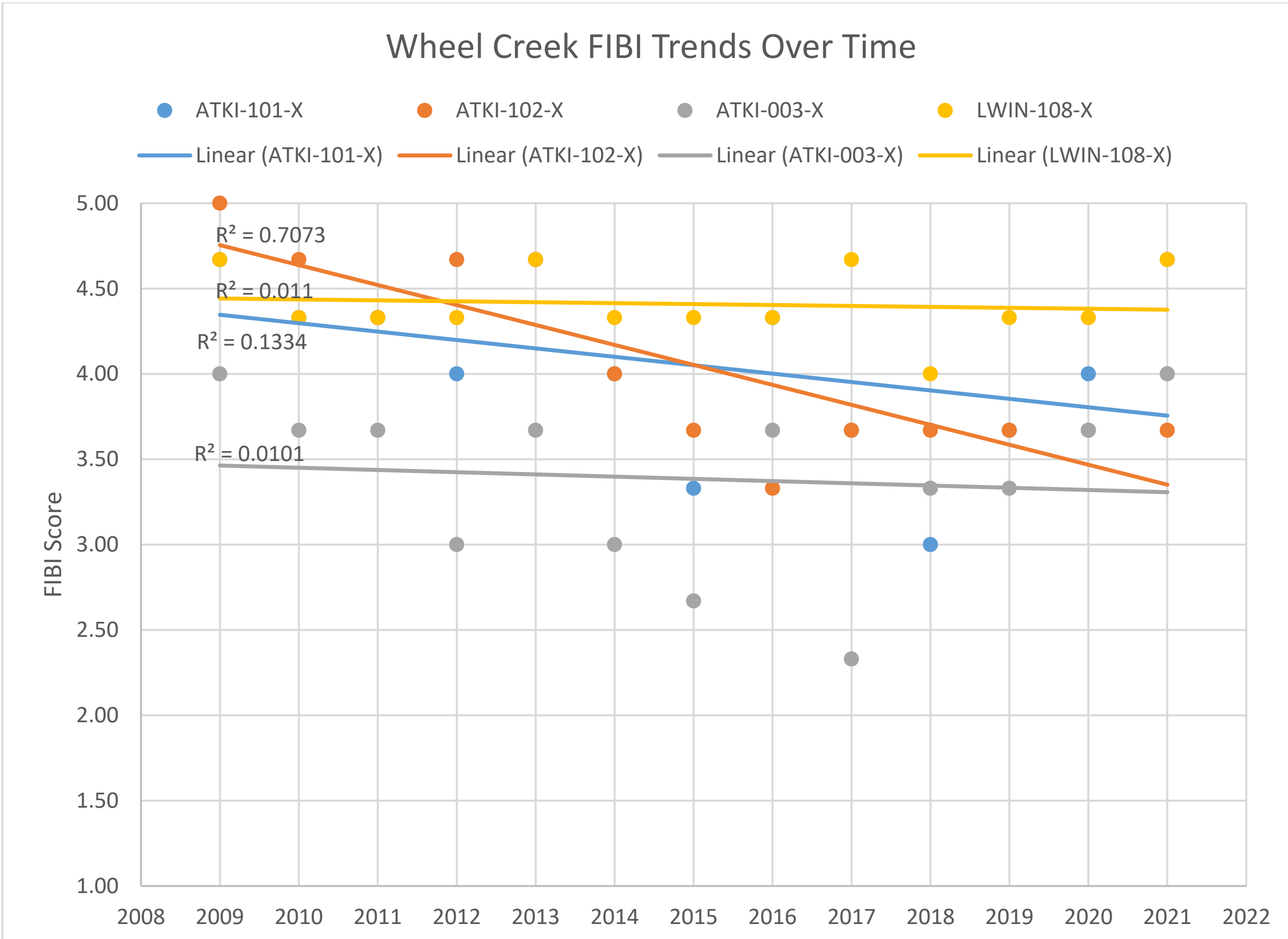

Figure 5 - FIBI Trends over time (2009 - 2021)

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Appendix A: Physical Habitat Data

Project Name: Wheel Creek Biological Monitoring
Project Number: 161602035.06
Prepared by: SLF Checked by: SKB
Prepared date: 6/29/2021 Checked date: 7/27/2021

PHI_Piedmont_v3_WheelCrk_2021.xlsx

		RAW DATA								SCALED METRICS								SCORES	
Site	Subshed Area (ac)*	Instream Habitat	Epifaunal Substrate	Embeddedness	Percent Shading	# Woody Debris/ Rootwads	Riffle Quality	Bank Stability	Remoteness Score	Instream Habitat	Epifaunal Substrate	Embeddedness	Percent Shading	# Woody Debris/ Rootwads	Riffle Quality	Bank Stability	Remoteness	PHI	PHI Rating
ATKI-101-X-2021	393.08	14	12	25	70	2	14	19	8	81.31	64.71	83.33	63.82	16.67	92.47	100.00	48.50	68.9	Partially Degraded
ATKI-102-X-2021	146.07	11	9	15	55	4	11	17	7	66.48	47.06	94.44	46.65	33.33	82.47	96.80	43.52	63.8	Degraded
ATKI-003-X-2021	105.03	13	11	20	55	10	13	17	6	80.59	58.82	88.89	44.62	83.33	94.41	95.55	37.82	73.0	Partially Degraded
LWIN-108-X-2021	411.86	12	12	20	85	7	13	15	9	68.41	64.71	88.89	77.06	58.33	87.13	90.04	54.03	73.6	Partially Degraded

Score	Narrative Rating
81-100	Minimally Degraded
66.0-80.9	Partially Degraded
51.0-65.9	Degraded
0-50.9	Severely Degraded

Appendix B: Benthic Macroinvertebrate Data

Project Name: Wheel Creek Monitoring 2021
Project Number: 161602035.06
Prepared by: SLF
Prepared date: 9/17/2021
Checked by: CRH
Checked date: 11/5/2021

2021_WheelCrk_Piedmont.xlsx
Version:

Metric	ATKI-101-X-2021	ATKI-102-X-2021	ATKI-003-X-2021	LWIN-108-X-2021	ATKI-003-X-2021 LD
Raw Scores					
Total Number of Taxa	22	17	23	16	13
Number of EPT Taxa	5	3	3	3	5
Number of Ephemeroptera Taxa	0	0	0	0	0
Percent Intolerant Urban	4.84	0.78	0.00	0.77	1.63
Percent Chironomidae	81	62	58.27	91.54	62.60
Percent Clingers	0.81	0.78	47.24	7.69	34.96
BIBI Scores					
Total Number of Taxa	3	3	3	3	1
Number of EPT Taxa	3	1	1	1	3
Number of Ephemeroptera Taxa	1	1	1	1	1
Percent Intolerant Urban	1	1	1	1	1
Percent Chironomidae	1	3	3	1	3
Percent Clingers	1	1	3	1	3
BIBI Score	***1.67***	***1.67***	***2.00***	***1.33***	***2.00***
Narrative Rating	***Very Poor***	***Very Poor***	***Poor***	***Very Poor***	***Poor***

Piedmont		Score	
Metric	**5**	**3**	**1**
Total Number of Taxa	≥25	15 - 24	<15
Number of EPT Taxa	≥11	5 - 10	<5
Number Ephemeroptera Taxa	≥4	2 - 3	<2
Percent Intolerant Urban	≥51	12 - 50	<12
Percent Chironomidae	≤24	24.01 - 63	>63
Percent Clingers	≥74	31 - 73.99	<31

Project Name: Wheel Creek Monitoring 2021
Project Number: 161602035.06
Prepared by: SLF Checked by: CRH
Prepared date: 9/14/2021 Checked date: 11/5/2021

2021_WheelCrk_Piedmont.xlsx
Version: 1
Site Name: -101-X-2021

Subphylum/ Class	Order	Family	Genus	Final ID	Note[1]	# of Org	FFG[2]	Habit[3]	Tolerance Value[4]
Insecta	Plecoptera	Nemouridae	Amphinemura	Amphinemura	I	1	Shredder	sp, cn	3
Insecta	Diptera	Tipulidae	Antocha	Antocha	I	1	Collector	cn	8
Insecta	Diptera	Chironomidae	Cardiocladius	Cardiocladius	I	10	Predator	bu, cn	10
Insecta	Trichoptera	Hydropsychidae	Ceratopsyche	Ceratopsyche	I	1	Collector	0	na
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche	I	5	Filterer	cn	6.5
Insecta	Trichoptera	Philopotamidae	Chimarra	Chimarra	I	3	Filterer	cn	4.4
Insecta	Diptera	Empididae	Clinocera	Clinocera	I	3	Predator	cn	7.4
Insecta	Diptera	Chironomidae	Corynoneura	Corynoneura	I	5	Collector	sp	4.1
Insecta	Diptera	Chironomidae	Diamesa	Diamesa	I	5	Collector	sp	8.5
Insecta	Diptera	Chironomidae	Eukiefferiella	Eukiefferiella	I	5	Collector	sp	6.1
Insecta	Odonata	Gomphidae	not identified	Gomphidae	I	1	Predator	bu	2.2
Insecta	Trichoptera	Hydropsychidae	Hydropsyche	Hydropsyche	I	1	Filterer	cn	7.5
0	0	0	not identified	Nematoda	U	1	0	0	na
Insecta	Diptera	Chironomidae	not identified	Orthocladiinae	P	1	Collector	0	7.6
Insecta	Diptera	Chironomidae	Orthocladius	Orthocladius	I/P	27	Collector	sp, bu	9.2
Insecta	Coleoptera	Elmidae	Oulimnius	Oulimnius	I	4	Scraper	cn	2.7
Insecta	Diptera	Chironomidae	Paratanytarsus	Paratanytarsus	I	1	Collector	sp	7.7
Insecta	Diptera	Chironomidae	Rheotanytarsus	Rheotanytarsus	I	2	Filterer	cn	7.2
Insecta	Diptera	Simuliidae	Simulium	Simulium	I	1	Filterer	cn	5.7
Insecta	Diptera	Chironomidae	Sympotthastia	Sympotthastia	I/P	43	Collector	sp	8.2
Insecta	Diptera	Chironomidae	Tanytarsus	Tanytarsus	I	1	Filterer	cb, cn	4.9
Insecta	Diptera	Chironomidae	Thienemannimyia gro	Thienemannimyia Grou	I	1	Predator	sp	8.2
Oligochaeta	Tubificida	Tubificidae	not identified	Tubificidae	U	1	Collector	cn	8.4

1 Life Stage, I - Immature, P- Pupa, A - Adult, U - Undetermined; 2 Functional Feeding Group; 3 Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer; 4 Tolerance Values, based on Hilsenhoff, modified for Maryland. An entry of "0" indicates information for the particular taxa was not available.

Project Name: Wheel Creek Monitoring 2021
Project Number: 161602035.06
Prepared by: SLF Checked by: CRH
Prepared date: 9/17/2021 Checked date: 11/5/2021

2021_WheelCrk_Piedmont.xlsx
Version: 1
Site Name: -102-X-2021

KCI TECHNOLOGIES

Subphylum/ Class	Order	Family	Genus	Final ID	Note[1]	# of Org	FFG[2]	Habit[3]	Tolerance Value[4]
Insecta	Diptera	Tipulidae	Antocha	Antocha	I	3	Collector	cn	8
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche	I	29	Filterer	cn	6.5
Insecta	Trichoptera	Philopotamidae	Chimarra	Chimarra	I	5	Filterer	cn	4.4
Insecta	Diptera	Chironomidae	Corynoneura	Corynoneura	I	5	Collector	sp	4.1
Insecta	Diptera	Chironomidae	Cricotopus	Cricotopus	I	15	Shredder	cn, bu	9.6
Insecta	Diptera	Chironomidae	Diamesa	Diamesa	I	2	Collector	sp	8.5
Insecta	Diptera	Chironomidae	Dicrotendipes	Dicrotendipes	I	2	Collector	bu	9
Insecta	Trichoptera	Hydropsychidae	Hydropsyche	Hydropsyche	I	7	Filterer	cn	7.5
0	0	0	not identified	Nematoda	U	1	0	0	na
Insecta	Diptera	Chironomidae	Orthocladius	Orthocladius	I/P	19	Collector	sp, bu	9.2
Insecta	Diptera	Chironomidae	Paratanytarsus	Paratanytarsus	I	17	Collector	sp	7.7
Insecta	Diptera	Chironomidae	Polypedilum	Polypedilum	I	1	Shredder	cb, cn	6.3
Insecta	Diptera	Chironomidae	Potthastia	Potthastia	I	1	Collector	sp	0.01
Insecta	Coleoptera	Elmidae	Stenelmis	Stenelmis	I	4	Scraper	cn	7.1
Insecta	Diptera	Chironomidae	Sympotthastia	Sympotthastia	I/P	7	Collector	sp	8.2
Insecta	Diptera	Chironomidae	Tanytarsus	Tanytarsus	I	5	Filterer	cb, cn	4.9
Insecta	Diptera	Chironomidae	Tvetenia	Tvetenia	I	5	Collector	sp	5.1

1 Life Stage, I - Immature, P- Pupa, A - Adult, U - Undetermined; 2 Functional Feeding Group; 3 Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer; 4 Tolerance Values, based on Hilsenhoff, modified for Maryland. An entry of "0" indicates information for the particular taxa was not available.

Project Name: Wheel Creek Monitoring 2021
Project Number: 161602035.06
Prepared by: SLF Checked by: CRH
Prepared date: 9/17/2021 Checked date: 11/5/2021

2021_WheelCrk_Piedmont.xlsx
Version: 1
Site Name: -003-X-2021

Subphylum/ Class	Order	Family	Genus	Final ID	Note[1]	# of Org	FFG[2]	Habit[3]	Tolerance Value[4]
Insecta	Diptera	Tipulidae	Antocha	Antocha	I	2	Collector	cn	8
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche	I	16	Filterer	cn	6.5
Insecta	Trichoptera	Philopotamidae	Chimarra	Chimarra	I	18	Filterer	cn	4.4
Insecta	Diptera	Empididae	Clinocera	Clinocera	I	3	Predator	cn	7.4
Insecta	Diptera	Chironomidae	Cricotopus	Cricotopus	I	10	Shredder	cn, bu	9.6
Insecta	Trichoptera	Hydropsychidae	Hydropsyche	Hydropsyche	I	2	Filterer	cn	7.5
Insecta	Collembola	Isotomidae	not identified	Isotomidae	U	1	0	0	4.8
Oligochaeta	Haplotaxida	Naididae	not identified	Naididae	U	1	Collector	bu	8.5
0	0	0	not identified	Nematoda	U	2	0	0	na
Insecta	Diptera	Empididae	Neoplasta	Neoplasta	I	3	Predator	0	na
Insecta	Diptera	Chironomidae	Orthocladius	Orthocladius	I/P	8	Collector	sp, bu	9.2
Insecta	Diptera	Chironomidae	Parametriocnemus	Parametriocnemus	I/P	18	Collector	sp	4.6
Insecta	Diptera	Chironomidae	Paratanytarsus	Paratanytarsus	I	1	Collector	sp	7.7
Insecta	Diptera	Chironomidae	Polypedilum	Polypedilum	I	1	Shredder	cb, cn	6.3
Insecta	Coleoptera	Psephenidae	Psephenus	Psephenus	I	1	Scraper	cn	4.4
Insecta	Diptera	Chironomidae	Rheotanytarsus	Rheotanytarsus	I	3	Filterer	cn	7.2
Insecta	Coleoptera	Elmidae	Stenelmis	Stenelmis	I	2	Scraper	cn	7.1
Insecta	Diptera	Chironomidae	Sympotthastia	Sympotthastia	I	17	Collector	sp	8.2
Insecta	Diptera	Chironomidae	Tanytarsus	Tanytarsus	I	1	Filterer	cb, cn	4.9
Insecta	Diptera	Chironomidae	Thienemannimyia gro	Thienemannimyia Group	I	3	Predator	sp	8.2
Insecta	Diptera	Tipulidae	Tipula	Tipula	I	1	Shredder	bu	6.7
Oligochaeta	Tubificida	Tubificidae	not identified	Tubificidae	U	1	Collector	cn	8.4
Insecta	Diptera	Chironomidae	Tvetenia	Tvetenia	I/P	12	Collector	sp	5.1

1 Life Stage, I - Immature, P- Pupa, A - Adult, U - Undetermined; 2 Functional Feeding Group; 3 Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer; 4 Tolerance Values, based on Hilsenhoff, modified for Maryland. An entry of "0" indicates information for the particular taxa was not available.

Project Name: Wheel Creek Monitoring 2021
Project Number: 161602035.06
Prepared by: SLF Checked by: CRH
Prepared date: 9/17/2021 Checked date: 11/5/2021

2021_WheelCrk_Piedmont.xlsx
Version: 1
Site Name: 3-X-2021 LD

Subphylum/ Class	Order	Family	Genus	Final ID	Note[1]	# of Org	FFG[2]	Habit[3]	Tolerance Value[4]
Insecta	Diptera	Tipulidae	Antocha	Antocha	I	2	Collector	cn	8
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche	I	10	Filterer	cn	6.5
Insecta	Trichoptera	Philopotamidae	Chimarra	Chimarra	I	18	Filterer	cn	4.4
Insecta	Diptera	Chironomidae	Chironomini	Chironomini	I	2	0	0	5.9
Insecta	Diptera	Empididae	Clinocera	Clinocera	I	5	Predator	cn	7.4
Insecta	Diptera	Chironomidae	not identified	Diamesinae	I/P	19	Collector	0	7.1
Insecta	Trichoptera	Hydropsychidae	Diplectrona	Diplectrona	I	1	Filterer	cn	2.7
Insecta	Trichoptera	Hydropsychidae	Hydropsyche	Hydropsyche	I	5	Filterer	cn	7.5
Insecta	Collembola	Isotomidae	not identified	Isotomidae	U	1	0	0	4.8
Insecta	Trichoptera	Uenoidae	Neophylax	Neophylax	I	1	Scraper	cn	2.7
Oligochaeta	not identified	not identified	not identified	Oligochaeta	U	2	Collector	bu	10
Insecta	Diptera	Chironomidae	not identified	Orthocladiinae	I/P	51	Collector	0	7.6
Insecta	Coleoptera	Elmidae	Stenelmis	Stenelmis	I	1	Scraper	cn	7.1
Insecta	Diptera	Chironomidae	not identified	Tanypodinae	I	1	Predator	0	7.5
Insecta	Diptera	Chironomidae	not identified	Tanytarsini	I	4	Collector	0	3.5

1 Life Stage, I - Immature, P- Pupa, A - Adult, U - Undetermined; 2 Functional Feeding Group; 3 Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer; 4 Tolerance Values, based on Hilsenhoff, modified for Maryland. An entry of "0" indicates information for the particular taxa was not available.

Project Name: Wheel Creek Monitoring 2021
Project Number: 161602035.06
Prepared by: SLF Checked by: CRH
Prepared date: 9/17/2021 Checked date: 11/5/2021

2021_WheelCrk_Piedmont.xlsx
Version: 1
Site Name: -108-X-2021

Subphylum/ Class	Order	Family	Genus	Final ID	Note[1]	# of Org	FFG[2]	Habit[3]	Tolerance Value[4]
Insecta	Diptera	Chironomidae	Ablabesmyia	Ablabesmyia	I	1	Predator	sp	8.1
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche	I	2	Filterer	cn	6.5
Insecta	Trichoptera	Philopotamidae	Chimarra	Chimarra	I	1	Filterer	cn	4.4
Insecta	Diptera	Chironomidae	Corynoneura	Corynoneura	I	5	Collector	sp	4.1
Insecta	Diptera	Chironomidae	Hydrobaenus	Hydrobaenus	I	5	Scraper	sp	7.2
Insecta	Trichoptera	Hydropsychidae	Hydropsyche	Hydropsyche	I	1	Filterer	cn	7.5
Oligochaeta	Haplotaxida	Naididae	not identified	Naididae	U	4	Collector	bu	8.5
Insecta	Diptera	Chironomidae	not identified	Orthocladiinae	P	1	Collector	0	7.6
Insecta	Diptera	Chironomidae	Orthocladius	Orthocladius	I/P	23	Collector	sp, bu	9.2
Insecta	Coleoptera	Elmidae	Oulimnius	Oulimnius	A	1	Scraper	cn	2.7
Insecta	Diptera	Chironomidae	Parametriocnemus	Parametriocnemus	I	5	Collector	sp	4.6
Insecta	Diptera	Chironomidae	Phaenopsectra	Phaenopsectra	I	1	Collector	cn	8.7
Insecta	Diptera	Chironomidae	Rheotanytarsus	Rheotanytarsus	I	3	Filterer	cn	7.2
Insecta	Diptera	Chironomidae	Sympotthastia	Sympotthastia	I/P	74	Collector	sp	8.2
Insecta	Diptera	Chironomidae	Thienemannimyia group	Thienemannimyia Group	I	1	Predator	sp	8.2
Insecta	Diptera	Tipulidae	Tipula	Tipula	I	1	Shredder	bu	6.7
Oligochaeta	Tubificida	Tubificidae	not identified	Tubificidae	U	1	Collector	cn	8.4

1 Life Stage, I - Immature, P- Pupa, A - Adult, U - Undetermined; 2 Functional Feeding Group; 3 Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer; 4 Tolerance Values, based on Hilsenhoff, modified for Maryland. An entry of "0" indicates information for the particular taxa was not available.

Appendix C: Fish Data

Project Name:	Wheel Creek Monitoring 2021		
Project Number:	161602035.06		
Prepared by:	SLF	Checked by:	SKB
Prepared date:	6/30/2021	Checked date:	7/27/2021

FIBI_WheelCrk_2021.xlsx

Site Name: ATKI-101-X-2020

Final ID	Scientific Name	Number of Organisms	Type	Tolerance	Trophic Status	Lithophilic Spawner	Composition	% Tolerant	% Generalists, Omnivores, Invertivores	Lithophilic Spawner	Adjusted No. Benthic Species	Abundance per Square Meter	Biomass per Square Meter
Blue Ridge Sculpin	*Cottus caeruleomentum*	359	SCULPIN	I	IS	Y	B	0	0	359	1	1.25	
Blacknose Dace	*Rhinichthys atratulus*	182	OTHRCYPR	T	OM	N	NOTYPE	182	182	0	0	0.63	
Bluntnose Minnow	*Pimephales notatus*	127	OTHRCYPR	T	OM	N	NOTYPE	127	127	0	0	0.44	
Creek Chub	*Semotilus atromaculatus*	81	OTHRCYPR	T	GE	Y	NOTYPE	81	81	81	0	0.28	
Common Shiner	*Luxilus cornutus*	77	SHINER	I	OM	Y	NOTYPE	0	77	77	0	0.27	
Redbreast Sunfish	*Lepomis auritus*	51	SUNFISH	NOTYPE	GE	N	NOTYPE	0	51	0	0	0.18	
Rosyside Dace	*Clinostomus funduloides*	20	OTHRCYPR	NOTYPE	IV	Y	NOTYPE	0	20	20	0	0.07	
Pumpkinseed	*Lepomis gibbosus*	10	SUNFISH	T	IV	N	NOTYPE	10	10	0	0	0.03	
Eastern Mosquitofish	*Gambusia holbrooki*	66	NOTYPE	NOTYPE	IV	N	NOTYPE	0	66	0	0	0.23	
Banded Killifish	*Fundulus diaphanus*	1	NOTYPE	NOTYPE	IV	N	NOTYPE	0	1	0	0	0.00	
Bluegill	*Lepomis macrochirus*	30	SUNFISH	T	IV	N	NOTYPE	30	30	0	0	0.10	
Fathead Minnow	*Pimephales promelas*	3	OTHRCYPR	NOTYPE	OM	N	NOTYPE	0	3	0	0	0.01	
Golden Shiner	*Notemigonus crysoleucas*	1	OTHRCYPR	T	OM	N	NOTYPE	1	1	0	0	0.00	
Cutlip Minnow	*Exoglossum maxillingua*	2	OTHRCYPR	NOTYPE	IV	Y	NOTYPE	0	2	2	0	0.01	
Longnose Dace	*Rhinichthys cataractae*	1	OTHRCYPR	NOTYPE	OM	N	NOTYPE	0	1	0	0	0.00	
Tessellated Darter	*Etheostoma olmstedi*	1	DARTER	T	IV	N	B	1	1	0	1	0.00	
	Total Count	*1012*						*42.69%*	*64.53%*	*53.26%*	*2.26*	3.53	*8.73*
	Total Biomass (g)	*2504*											

Project Name: Wheel Creek Monitoring 2021
Project Number: 161602035.06
Prepared by: SLF Checked by: SKB
Prepared date: 6/30/2021 Checked date: 7/27/2021

FIBI_WheelCrk_2021.xlsx

Site Name: ATKI-102-X-2020

Final ID	Scientific Name	Number of Organisms	Type	Tolerance	Trophic Status	Lithophilic Spawner	Composition	% Tolerant	% Generalists, Omnivores, Invertivores	Lithophilic Spawner	Adjusted No. Benthic Species	Abundance per Square Meter	Biomass per Square Meter
Blacknose Dace	*Rhinichthys atratulus*	487	OTHRCYPR	T	OM	N	NOTYPE	487	487	0	0	3.82	
Creek Chub	*Semotilus atromaculatus*	190	OTHRCYPR	T	GE	Y	NOTYPE	190	190	190	0	1.49	
Blue Ridge Sculpin	*Cottus caeruleomentum*	143	SCULPIN	I	IS	Y	B	0	0	143	1	1.12	
White Sucker	*Catostomus commersonii*	1	SUCKER	T	OM	Y	NOTYPE	1	1	1	0	0.01	
	Total Count	*821*						*82.58%*	*82.58%*	*40.68%*	*2.89*	6.44	*18.10*
	Total Biomass (g)	*2308*											

Project Name:	Wheel Creek Monitoring 2021		
Project Number:	161602035.06		
Prepared by:	SLF	Checked by:	SKB
Prepared date:	6/30/2021	Checked date:	7/27/2021

FIBI_WheelCrk_2021.xlsx

Site Name: ATKI-003-X-2020

Final ID	Scientific Name	Number of Organisms	Type	Tolerance	Trophic Status	Lithophilic Spawner	Composition	% Tolerant	% Generalists, Omnivores, Invertivores	Lithophilic Spawner	Adjusted No. Benthic Species	Abundance per Square Meter	Biomass per Square Meter
Blacknose Dace	*Rhinichthys atratulus*	168	OTHRCYPR	T	OM	N	NOTYPE	168	168	0	0	0.88	
Creek Chub	*Semotilus atromaculatus*	262	OTHRCYPR	T	GE	Y	NOTYPE	262	262	262	0	1.37	
Blue Ridge Sculpin	*Cottus caeruleomentum*	36	SCULPIN	I	IS	Y	B	0	0	36	1	0.19	
White Sucker	*Catostomus commersonii*	2	SUCKER	T	OM	Y	NOTYPE	2	2	2	0	0.01	
Goldfish	*Carassius auratus*	1	OTHRCYPR	NOTYPE	OM	N	NOTYPE	0	1	0	0	0.01	
	Total Count	*469*						*92.11%*	*92.32%*	*63.97%*	*6.00*	2.45	*8.81*
	Total Biomass (g)	*1685*											

Project Name:	Wheel Creek Monitoring 2021		
Project Number:	161602035.06		
Prepared by:	SLF	Checked by:	SKB
Prepared date:	6/30/2021	Checked date:	7/27/2021

FIBI_WheelCrk_2021.xlsx

Site Name: LWIN-108-X-2020

Final ID	Scientific Name	Number of Organisms	Type	Tolerance	Trophic Status	Lithophilic Spawner	Composition	% Tolerant	% Generalists, Omnivores, Invertivores	Lithophilic Spawner	Adjusted No. Benthic Species	Abundance per Square Meter	Biomass per Square Meter
Blue Ridge Sculpin	*Cottus caeruleomentum*	148	SCULPIN	I	IS	Y	B	0	0	148	1	0.38	
Blacknose Dace	*Rhinichthys atratulus*	46	OTHRCYPR	T	OM	N	NOTYPE	46	46	0	0	0.12	
Bluntnose Minnow	*Pimephales notatus*	28	OTHRCYPR	T	OM	N	NOTYPE	28	28	0	0	0.07	
Rosyside Dace	*Clinostomus funduloides*	71	OTHRCYPR	NOTYPE	IV	Y	NOTYPE	0	71	71	0	0.18	
Common Shiner	*Luxilus cornutus*	11	SHINER	I	OM	Y	NOTYPE	0	11	11	0	0.03	
White Sucker	*Catostomus commersonii*	5	SUCKER	T	OM	Y	NOTYPE	5	5	5	0	0.01	
American Eel	*Anguilla rostrata*	22	NOTYPE	NOTYPE	GE	N	NOTYPE	0	22	0	0	0.06	
Creek Chub	*Semotilus atromaculatus*	61	OTHRCYPR	T	GE	Y	NOTYPE	61	61	61	0	0.16	
Fallfish	*Semotilus corporalis*	1	OTHRCYPR	I	GE	Y	NOTYPE	0	1	1	0	0.00	
Redbreast Sunfish	*Lepomis auritus*	2	SUNFISH	NOTYPE	GE	N	NOTYPE	0	2	0	0	0.01	
Longnose Dace	*Rhinichthys cataractae*	6	OTHRCYPR	NOTYPE	OM	N	NOTYPE	0	6	0	0	0.02	
Margined Madtom	*Noturus insignis*	2	MADTOM	I	IV	N	B	0	2	0	1	0.01	
	Total Count	*403*						*34.74%*	*63.28%*	*73.70%*	*2.20*	1.03	*8.83*
	Total Biomass (g)	*3445*											

Appendix D: Supplemental Flora/Fauana Data

ATKI-101-X

Invasive Plants	Relative Abundance
Japanese barberry	Present
Japanese stiltgrass	Extensive
Wineberry	Present
Multiflora rose	Present

Stream Salamanders
Nothern Two-lined Salamander

Other Herpetofauna
Northern green frog
Queen snake
Pickerel frog

Crayfish
Faxonius virilis

ATKI-102-X

Invasive Plants	Relative Abundance
Japanese honeysuckle	Present
Japanese stiltgrass	Present
Oriental bittersweet	Present
Multiflora rose	Present
Mile-a-minute	Present

Stream Salamanders
Nothern Two-lined Salamander

Other Herpetofauna
Northern green frog
Northern watersnake
Cope's gray tree frog

Crayfish
Faxonius virilis

ATKI-003-X

Invasive Plants	Relative Abundance
Japanese stiltgrass	Extensive
Japanese barberry	Present
Oriental bittersweet	Present
Japanese honeysuckle	Present
Multiflora rose	Present
Mile-a-minute	Present
Privet	Present

Stream Salamanders
None Observed

Other Herpetofauna
Northern green frog
Pickerel frog

Crayfish
Faxonius virilis

LWIN-108-X

Invasive Plants	Relative Abundance
Japanese stiltgrass	Present
Multiflora rose	Present

Stream Salamanders
Nothern Two-lined Salamander

Other Herpetofauna
Northern green frog

Crayfish
None Observed

WHEEL CREEK GEOMORPHIC ASSESSMENT POST-RESTORATION YEAR 4 FINAL REPORT

VERSAR

Your Needs. Our Mission.

HARFORD COUNTY MARYLAND

AT THE RISQUE OF OUR LIVES AND FORTUNES 1773

November 4, 2020

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WHEEL CREEK
GEOMORPHIC ASSESSMENT
POST-RESTORATION YEAR 4 FINAL REPORT

Prepared for:

Harford County
Department of Public Works
Division of Highways and Water Resources
212 South Bond Street
Bel Air, Maryland 21014

Prepared by

Versar, Inc.
9200 Rumsey Road, Suite 1
Columbia, Maryland 21045

November 4, 2020

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1.0 INTRODUCTION

Harford County Department of Public Works (DPW) has completed the restoration of the Wheel Creek watershed, which is located in the Bush River Basin in the central portion of Harford County near Bel Air (Figure 1-1). The restoration is the result of previous planning efforts including the Bush River Watershed Restoration Strategy (WRAS), the Bush River Watershed Management Plan in 2003, and the Wheel Creek Watershed Assessment completed in 2008.

Restoration efforts in this watershed began in September 2012 with the retrofit of a stormwater management facility (Pond A) located at the Gardens of Bel Air, and construction was completed in December of 2012. A second project, the Calvert's Walk stream restoration project, began in January of 2013 and was completed that April. In 2015, two more stormwater management facilities were retrofitted, Pond C in August and Pond D in December. The final phase of implementation was completed in March of 2017. These projects included the Lower Wheel Creek stream restoration and the retrofit of the final stormwater management facility (Pond E).

As part of implementing the restoration efforts, the County was awarded funds from a Local Government Implementation Grant through the Chesapeake and Atlantic Coastal Bays 2010 and 2016 Trust Funds. Under the grant proposal, the County planned to implement a total of four stormwater retrofits and five stream restoration projects to improve water quality, decrease stormwater discharges, and improve instream habitat.

Beginning in 2009, the County initiated monitoring to demonstrate measurable reductions of sediment and nutrients, improvement in physical stability and instream habitat, and improvement in fish and benthic macroinvertebrates communities. As a collaborative monitoring effort, Harford County DPW, Maryland Department of Natural Resources (DNR), the United States Geologic Survey (USGS), and two consulting firms (KCI Technologies and Versar, Inc.) have performed select data collection activities. The study design was developed to compare Pre-Construction conditions (i.e., baseline conditions) to future Post-Construction restoration conditions. This report focuses on seven years of geomorphic monitoring, conducted by KCI and Versar. Data generated by other project partners includes:

- USGS – flow gaging at the downstream end of Wheel Creek (5-minute interval discharge record);
- Maryland DNR (Up to July 2016)/Versar (July 2016 to present) – flow gaging at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court (5-minute interval discharge record);
- KCI – Biological and physical habitat data; and
- Versar – Storm runoff water chemistry and water quality monitoring including nutrient and sediment data at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court (pollutant loads for the measured parameters for each sampled event)

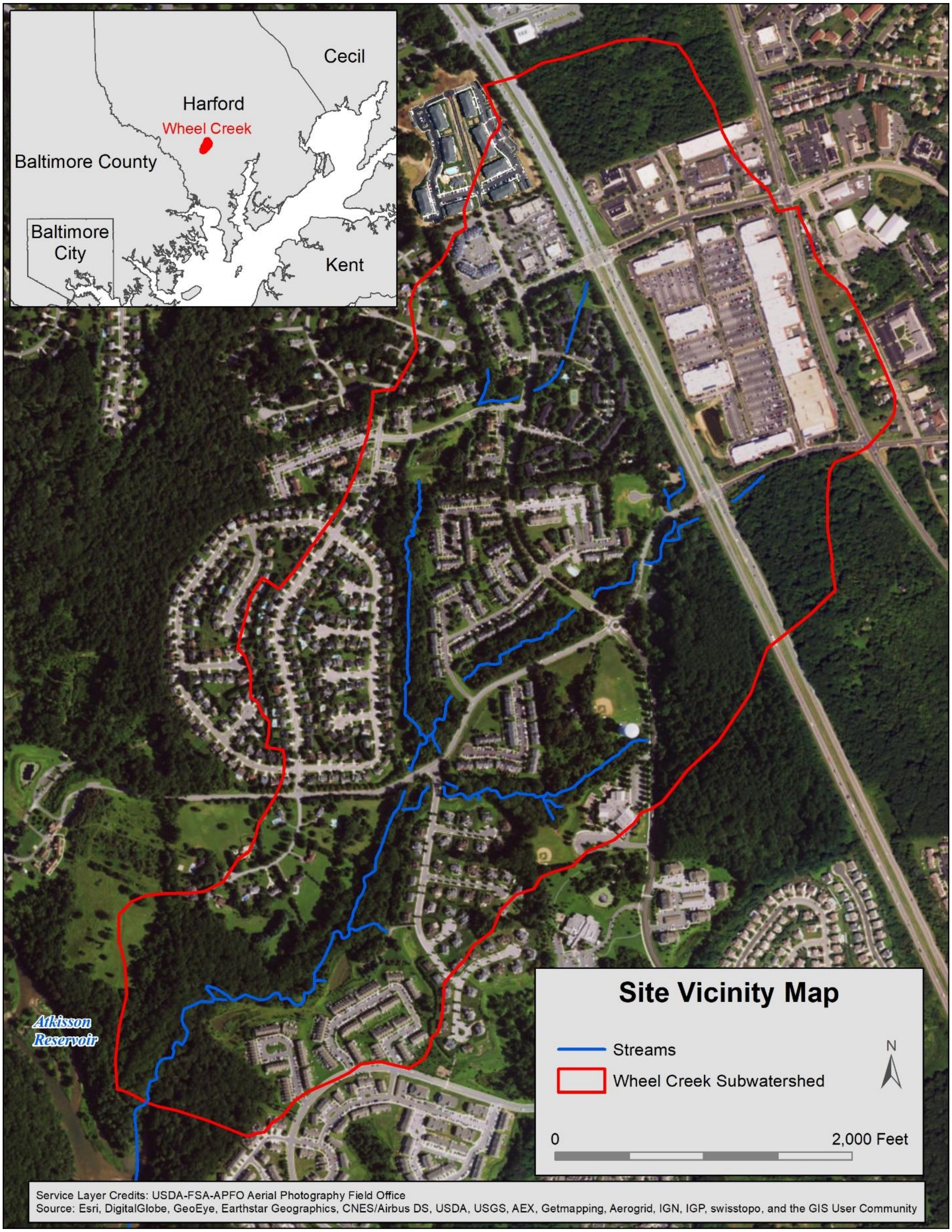

Figure 1-1. Site vicinity map

- Harford County DPW (Up to March 2019)/Versar (April 2019 to present) – Baseflow nutrient and total suspended solids data at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court.

Assessment and monitoring of the physical geomorphologic conditions was initially performed by KCI in 2010 (Pre-Restoration Year 1) to evaluate baseline conditions and was continued by Versar in 2012 (Pre-Restoration Year 2), 2013 (Pre-Restoration Year 3), 2015 (Pre-Restoration Year 4), 2017 (Post-Restoration Year 1), 2018 (Post-Restoration Year 2), 2019 (Post-Restoration Year 3), and 2020 (Post-Restoration Year 4). The geomorphic monitoring program was designed to assess the geomorphic stability of the stream channels in the Wheel Creek watershed as they respond to restoration activities. The geomorphic monitoring includes surveying and analyzing monumented cross-sections and longitudinal profiles at four (4) reaches (Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 4), monitoring bankpins and scour chains (Pre-Restoration Year 1 through 4 only), mapping substrate facies (Pre-Restoration Year 1 only), and evaluating substrate particle size distribution (Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 4). The methods evaluate bed and bank stability, channel profile, and bed features. For a complete description of the Year 1 Study see *Wheel Creek Watershed Restoration Project, Pre-Construction Monitoring, Baseline Conditions, 2009-2011* (KCI, 2012). For a complete description of the Year 2, Year 3, and Year 4 Studies see *Wheel Creek Geomorphic Assessment Year 2* (Versar, 2013), *Wheel Creek Geomorphic Assessment Year 3* (Versar, 2014) and *Wheel Creek Geomorphic Assessment Year 4* (Versar, 2015). For a complete description of the Post-Restoration Year 1 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 1 Final Report* (Versar, 2017), Year 2 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 2 Final Report* (Versar, 2018), and Year 3 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 3 Final Report* (Versar, 2019). This report focuses on continued geomorphic monitoring, including a comparison of data collected during Pre-Restoration Years 1, 2, 3, 4, and Post-Restoration Years 1, 2, 3, and 4.

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2.0 METHODOLOGIES

2.1 GEOMORPHIC ASSESSMENT

The primary goal of the geomorphic monitoring is to assess the geomorphic stability of the stream channels in the Wheel Creek watershed as they respond to restoration activities. Assessment techniques include a survey of permanently-monumented channel cross-sections, a longitudinal profile survey, particle size analysis, substrate facies mapping (Pre-Restoration Year 1 only), and assessment of bank pins and scour chains (Pre-Restoration Years 1 through 4 only). In 2010, four (4) assessment reaches (Figure 2-1) were established by KCI for geomorphic monitoring based on the following treatments:

1. within a stream stabilization reach (WC01);
2. within a stream stabilization reach and downstream of a retrofitted stormwater management facility (WC02);
3. downstream of a retrofitted stormwater management facility (WC03); and
4. a control site with no proposed restoration activities (WC04).

These reaches were re-surveyed by Versar in 2012, 2013, 2015, 2017, 2018, 2019, and 2020 to provide additional monitoring data. Cross-sectional and longitudinal profile surveys were first conducted to establish baseline conditions of channel geometry and slope. Subsequent survey data can be compared to the baseline data to determine whether lateral or vertical migration of the channel is occurring and to document any changes that have occurred in the restored reaches. Bank and bed pins were monitored to determine rates of potential bank and channel bed erosion or aggradation, while scour chains were used to quantify the extent of bed material scouring. The bank and bed pins along with the scour chains have been discontinued from the monitoring following Pre-Restoration Year 4 (2015). Pebble counts were conducted to assess substrate particle size distribution and track changes in channel roughness. Detailed methods are described below.

2.1.1 Longitudinal Profile and Cross-sectional Surveys

KCI installed and surveyed three (3) benchmark monuments at each reach during the initial baseline monitoring effort (2010) to establish consistent survey elevations from year to year, as well as start and end points for each survey reach. Two benchmarks (one concrete monument and one capped iron rebar pin) were placed on either side of the channel, whereby a measuring tape run from the left bank pin to the right bank monument marks the starting point (i.e., station 0+00) in the channel for the longitudinal profile. The concrete monument was set in 2-inch PVC piping to a depth of 30 inches, with a rounded stove bolt set in the concrete to establish the monumented benchmark elevation, which will be used to compare longitudinal profiles over time. A third monument (capped iron rebar) was placed at the upstream end of the reach to mark the end of the survey reach. Versar re-surveyed these benchmarks at WC03 and WC04 during the Post-Restoration Years 1, 2, 3, and 4 efforts to enable overlays between past surveys.

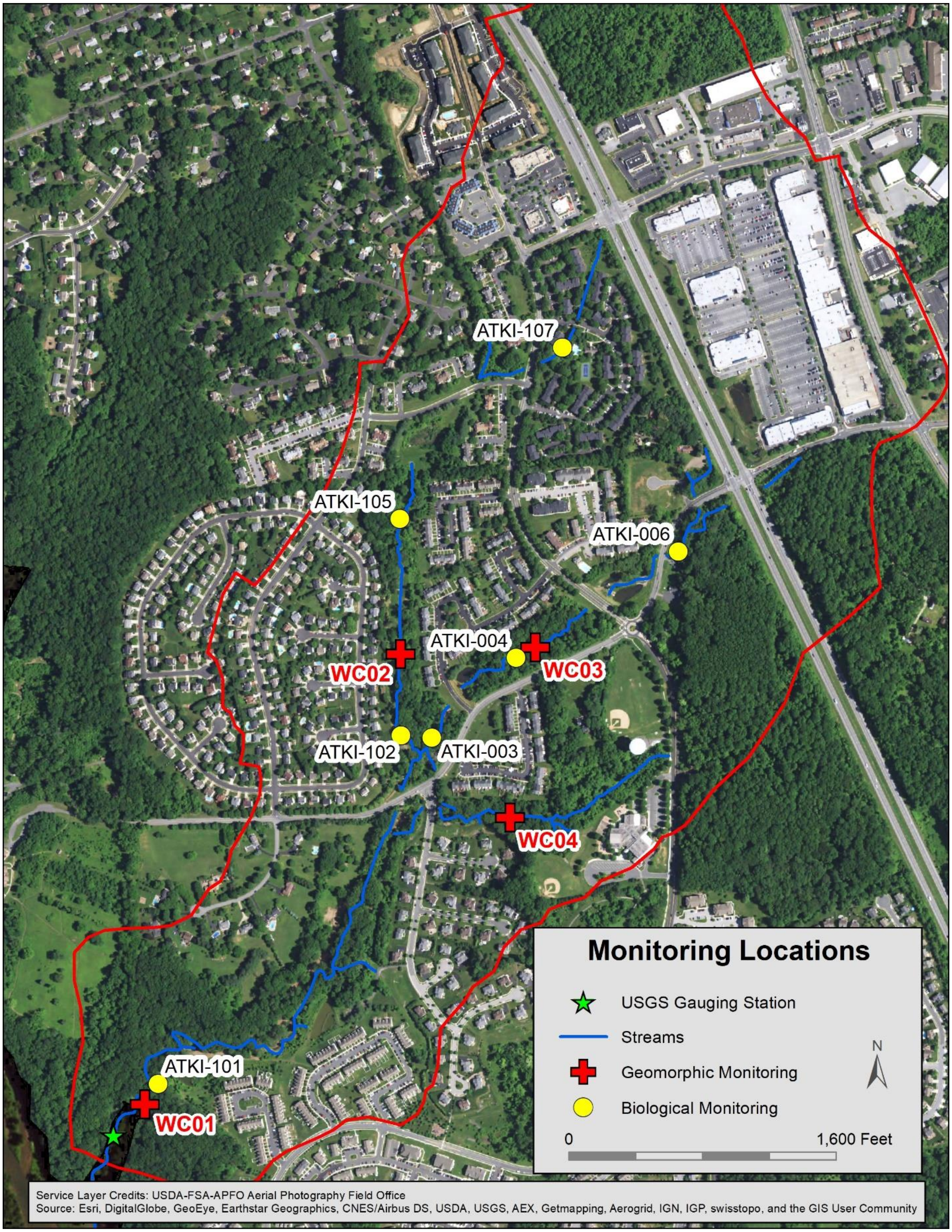

Figure 2-1. Wheel Creek monitoring locations

Versar re-established reaches WC01 and WC02 in 2017 for Post-Restoration Year 1 monitoring. Three (3) benchmark monuments were again installed at both reaches. Two capped iron rebar monuments were installed on each side of the channel to mark the starting point of the new longitudinal profile (i.e., station 0+00). An additional capped iron rebar monument was installed upstream marking the end of the longitudinal profile. These were re-surveyed in 2018, 2019, and 2020.

A longitudinal profile of each reach was surveyed using a laser level, calibrated stadia rod, and 300-foot measuring tape following the procedure outlined in Harrelson et al. (1994). The longitudinal profiles were initially established to encompass a minimum reach length of approximately 20 bankfull widths or 300 feet, measured along the centerline of each bankfull channel. Each reach was started at the top of a feature located at the downstream benchmarks, and finished at the top of a feature at or above the upstream benchmark. Each reach included a survey of breakpoints in and between bed features and delineation of riffle, run, pool, and glide features. A survey of the bankfull elevation (where discernible), top of bank, and water surface was also performed. At each site where instream restoration activities did not occur (WC03 and WC04), the plotted Post-Restoration Years 1 through 4 longitudinal profiles were overlaid with the plots from Pre-Restoration Years 1 through 4. These plots enable comparisons between years and are used to track changes that occur in the bed sequences and channel slopes. At the two sites where instream restoration occurred (reaches WC01 and WC02), the plotted profiles from Pre-Restoration Years 1 through 4 were overlaid and the Post-Restoration Years 1 through 4 plotted profiles were compared.

In order to establish locations where fluvial geomorphic characteristics of the channel could be measured and compared from one year to the next for assessing bed and bank stability, KCI established permanent cross-sections at two (2) locations within each monitoring reach during Pre-Restoration Year 1; one located on a meander bend and one within a riffle feature. KCI established monuments (one concrete and one capped iron rebar) on either side of the channel to mark the cross-section locations and benchmark elevations. Concrete monuments were set in 2-inch PVC piping to a depth of 30 inches, with a rounded metal stove bolt set in the concrete to mark the monumented elevation. Wherever possible, the monuments were set flush to the ground surface for safety concerns, and the location of each monument was recorded using a GPS unit capable of sub-meter accuracy.

Permanent cross-sections were established in 2010 and surveyed during Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 4 within each reach at profile stations as shown in Table 2-1. Stationing differed slightly at several stations due to channel migration over time or as a result of re-installing a cross-section when instream restoration has occurred. Cross-sections located in reaches WC01 and WC02 were re-established with new benchmarks in Post-Restoration Year 1 (2017). Due to ongoing restoration construction activities, the WC01 left end pin at Cross-section 2 had to be reinstalled in 2018, as it could not be located during the Post-Restoration Year 2 survey. Reaches WC03 and WC04 were still monumented to the original benchmarks installed in Pre-Restoration Year 1 (2010) since no instream restoration occurred at those locations. However, the WC03 right end pin at Cross-section 2 had to be reinstalled in 2019, as it had eroded away and fallen into the stream channel during the Post-Restoration Year 3 survey. The same methods were used to establish the new cross-sections in these reaches, although the corresponding station on the longitudinal profile will not be comparable to previous years of Pre-Restoration surveying.

Table 2-1. Cross-sectional survey locations

Reach	WC01*		WC02*		WC03		WC04	
Profile Station (Pre-Year 1)	2+30	2+95	1+37	3+24	1+55	2+07	1+08	1+68
Profile Station (Pre-Year 2)	2+30	2+95	1+38	3+24	1+57	2+08	1+08	1+68
Profile Station (Pre-Year 3)	2+29	2+95	1+38	3+25	1+56	2+12	1+08	1+68
Profile Station (Pre-Year 4)	2+29	2+95	1+38	3+24	1+55	2+07	1+08	1+68
Profile Station (Post-Year 1)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Profile Station (Post-Year 2)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Profile Station (Post-Year 3)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Profile Station (Post-Year 4)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Feature	Riffle	Meander/ Pool	Riffle	Pool	Riffle	Meander/ Run	Meander/ Pool	Riffle

*Cross-sections re-established during Post-Restoration Year 1

During Post-Restoration Year 4, Versar resurveyed the cross-sections using a laser level, calibrated stadia rod, and measuring tape following the procedure outlined in Harrelson et al. (1994). The cross-sectional surveys captured features of the floodplain, monuments, and all pertinent channel features including:

- Top of bank
- Bankfull elevation
- Edge of water
- Limits of point and instream depositional features
- Thalweg
- Floodprone elevation

Longitudinal profile and cross-sectional data were entered into *The Reference Reach Spreadsheet* version 4.3L (ODNR, 2012) for data analysis and graphical interpretation. Profile and cross-sectional data collected in 2010, 2012, 2013, 2015, 2017, 2018, 2019, and 2020 provide eight years of data to which subsequent monitoring events will be overlaid and/or compared to assess changes in channel dimension, pattern, and profile.

For the purpose of this report, bankfull elevations were selected based upon bankfull indicators observed in the field. Channel geometry and cross-sectional areas were calculated using *The Reference Reach Spreadsheet* (ODNR, 2012). Because bankfull indicators are not always easily discernible from year to year and best professional judgment is often required to determine bankfull elevations, top of bank features were also measured. Top of low bank cross-sectional areas were also calculated and can be utilized for future monitoring events to generate hydraulic geometry values that are more directly comparable between each monitoring effort.

2.1.2 Particle Size Analysis

Channel substrate composition (e.g., gravel, sand, silt) is an important aspect of a stream's biological and geomorphic character. The substrate size and complexity affects the stream's available habitat for benthic fauna and determines a channel's roughness, which influences the channel flow characteristics. To quantify the distribution of channel substrate particle sizes within the study area, modified Wolman pebble counts (Wolman, 1954; Harrelson et al., 1994) were performed. A total of three (3) pebble counts were conducted within each monitoring reach; one (1) feature-specific pebble count was conducted at each cross-section location within the cross-sectional bed feature (two (2) total within each reach), and one (1) weighted pebble count was conducted throughout the entire reach based on the proportion of bed features (e.g., riffle, run, pool, glide) present within the survey reach. Feature-specific pebble counts were performed via 10 evenly-spaced transects positioned throughout the survey feature, and 10 particles (spaced as evenly as possible) were measured across the bankfull channel of each transect for a total of 100 particles. The weighted (proportional) pebble count was conducted at 10 transects positioned throughout the entire reach based on the proportion of bed features, and 10 particles (spaced as evenly as possible) were measured across the bankfull channel of each transect for a total of 100 particles. For both types of counts, particles were chosen without visual bias by reaching forth with an extended finger into the stream bed while looking away and choosing the first particle that comes in contact with the sampler's finger. All particles were then measured across the intermediate axis using a gravelometer and resultant data were entered into *The Reference Reach Spreadsheet* (ODNR, 2012). The results of each weighted pebble count were used to determine the median particle size (i.e., D_{50}) of the specific reach. Additionally, the D_{84} was calculated from the feature pebble counts to determine the particle size that 84 percent of the sample is of the same size or smaller. The D_{84} particles were used in calculating channel velocity and discharge. Results from Versar's Post-Restoration Year 4 evaluations were compared to those found during the previous years of monitoring to evaluate changes in channel substrate composition and stability.

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3.0 RESULTS AND DISCUSSION

3.1 FLUVIAL GEOMORPHIC ASSESSMENT

3.1.1 Longitudinal Profiles and Cross-sectional Surveys

The fourth year of Post-Restoration longitudinal profile and cross-sectional surveys was completed between June 5th and June 17th, 2020. While performing the longitudinal profile, bed features including riffles, runs, pools, glides, bankfull indicators (where readily discernible), and water surface were noted to sufficiently assess conditions. The longitudinal profile data were analyzed to calculate the water surface slope and proportion of bed features for each monitoring reach (Table 3-1). These data will be compared to previous and subsequent annual monitoring data to track potential changes in the overall channel slope. Refer to Appendix A for photographs depicting the overall site conditions during the Post-Restoration Year 4 survey. Graphical depictions of each profile are presented in Appendix B. In addition, each surveyed profile was plotted, but only overlain and compared to the Pre-Restoration Years 1, 2, 3, and 4 profiles at WC03 and WC04 (Appendix C) and will be compared to subsequent annual surveyed profiles in order to assess changes occurring in the bed structure. Due to instream restoration activities, WC01 and WC02 Post-Restoration overlays do not share the same monuments as Pre-Restoration. Therefore, separate Post-Restoration overlays were created for these reaches.

Table 3-1. Results of longitudinal profile survey – Post-Restoration Year 4

Reach	Length (ft)	Slope	Proportion of Features			
			Riffle	Run	Pool	Glide
WC01*	490	2.7%	35.6%	17.2%	27.8%	19.4%
WC02*	340	2.2%	49.7%	9.3%	23.6%	17.4%
WC03	308	1.8%	42.6%	7.4%	35.4%	14.6%
WC04	300	3.5%	57.2%	18.3%	16.2%	8.3%

*Profiles re-established during Post-Restoration Year 1

Cross-sectional surveys were analyzed at each of the eight permanent monitoring locations to determine bankfull width, mean depth, width/depth ratio, and overall cross-sectional area during baseline conditions. Since bankfull elevation is based on field indicators and can be somewhat subjective to determine in the field, top-of-bank elevation was also calculated and will be utilized to track changes in the cross-sectional dimensions listed below. Results of the cross-sectional measurements are included in Table 3-2 and graphical depictions of each section are presented in Appendix B. In addition, each surveyed section was plotted, overlain (where appropriate) and compared to the Pre-Construction year 1, 2, 3, and 4 graphs (Appendix C) and will be compared to subsequent annual cross-section graphs in order to assess changes to channel dimensions post-restoration.

Table 3-2. Results of cross-sectional survey analysis – Post-Restoration Year 4									
Reach	**Station**	**Feature**	**Bankfull Width (ft)**	**Mean Depth (ft)**	**Width/ Depth Ratio**	**Entrench-ment Ratio**	**Bankfull Area (ft^2)**	**Top of Bank Area (ft^2)**
WC01*	2+24	Crossover/Riffle	24.5	0.9	27.0	1.7	22.1	148.4
	2+71	Meander/Pool	13.9	1.8	7.6	2.1	25.4	144.7
WC02*	0+74.5	Crossover/Riffle	11.9	0.6	18.6	1.2	7.6	35.3
	1+10	Pool	14.8	0.4	38.1	1.3	5.7	21.8
WC03	1+56	Crossover/Riffle	10.7	0.7	15.2	1.6	7.6	40.5
	2+08	Meander/Run	13.0	1.3	10.4	2.7	16.2	32.1
WC04	1+10	Meander/Pool	7.8	0.7	10.5	4.2	5.8	90.9
	1+68	Crossover/Riffle	9.4	0.3	27.4	1.4	3.3	55.7
*Cross-sections were re-established during Post-Restoration Year 1								

3.1.2 Particle Size Analysis

The results of the pebble count data collected during the Post-Restoration Year 4 monitoring are shown in Table 3-3. Reachwide and riffle surface pebble counts indicate a D_{50} median particle size class ranging from coarse gravel to small cobble across all sites. Meander feature surface pebble counts indicate a D_{50} ranging from medium gravel to very coarse gravel, due to pool features yielding smaller particles which is especially evident at the control WC03 meander/pool cross-section. Riffle surface and reachwide D_{84} size classes range from small cobble to large cobble at all sites, with the largest particles found at sites WC01 and WC02. Similarly, meander feature surface pebble counts at all sites indicate a D_{84} median particle size class ranging from very coarse gravel to medium cobble. Complete particle size distribution charts are included in Appendix B.

Table 3-3. Particle size distribution – Post-Restoration Year 4								
Riffle Feature Surface			***Meander Feature Surface***			***Reachwide***		
Measure	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**
*WC01**								
D_{50}	42	very coarse gravel	D_{50}	25	coarse gravel	D_{50}	32	coarse gravel
D_{84}	110	medium cobble	D_{84}	84	small cobble	D_{84}	93	medium cobble
*WC02**								
D_{50}	82	small cobble	D_{50}	43	very coarse gravel	D_{50}	37	very coarse gravel
D_{84}	150	large cobble	D_{84}	100	medium cobble	D_{84}	80	small cobble
WC03								
D_{50}	36	very coarse gravel	D_{50}	12	medium gravel	D_{50}	31	coarse gravel
D_{84}	77	small cobble	D_{84}	44	very coarse gravel	D_{84}	71	small cobble
WC04								
D_{50}	49	very coarse gravel	D_{50}	20	coarse gravel	D_{50}	22	coarse gravel
D_{84}	92	medium cobble	D_{84}	58	very coarse gravel	D_{84}	75	small cobble

4.0 COMPARISONS BETWEEN YEARS

4.1 WC01

This site exhibited the most drastic changes in longitudinal profile over the four years of Pre-Restoration monitoring (2010-2015; Figure C-1). At the downstream-most part of the reach, the stream's thalweg followed along the left bank outside bend during the first year of survey with a large mid-channel bar separating the thalweg from a cutoff channel along the right bank. During the second and third years of monitoring (2012, 2013), the thalweg followed what had been the cutoff channel along the right bank and the previous thalweg channel had only minimal flows. During the fourth year of survey (2015) the thalweg continued to follow the channel along the right bank. Furthermore, a large tree along the left bank fell and was perpendicularly positioned in the stream through this section. The tree caused the stream to widen and flow over most of the mid-channel bar; however, during years 1 through 3 of Post-Restoration monitoring, the tree migrated onto the left bank, laying parallel, and the outside left bend channel now conveyed the majority of stream flow. During the year 4 Post-Restoration survey in 2020, channel conditions at this location were found to have aggraded substantially, and now the majority of stream flow occurs mid-channel throughout this portion of the profile. At the upstream-most part of the reach, the stream's pattern also changed. Stationing differed from above Cross-section 2 (Station 2+95) to the end of the reach. During the first year of monitoring (2010), the reach was 400 feet from top to bottom, but during all other years of Pre-Restoration monitoring the reach was 420 feet in length. Sinuosity above Cross-section 2 likely increased, adding length to the profile.

Changes in the cross-sections were also observed at WC01 between the four years of Pre-Restoration survey (Figures C-7, C-9). Bed scour was observed at Cross-section 1 (Crossover Riffle at Station 2+29) especially near the right bank between Pre-Restoration Years 1 and 2, while deposition was apparent near the left bank between Pre-Restoration Years 2 and 3. During Pre-Restoration Year 4, continued deposition was observed, and the cross-section once again closely resembled that of Pre-Restoration Year 1. Significant bank erosion and undercutting along the left bank (almost 6 feet) was observed at Cross-section 2 (Meander Bend at Station 2+95) during both the second and third years of monitoring (2012, 2013). Between Pre-Restoration Years 3 and 4, continued erosion occurred along the left bank increasing the depth of undercutting. Eroded sediment caused slight deposition along the left stream bed. This resulted in increases, from Pre-Restoration Year 1, of bankfull cross-sectional area and top of bank cross-sectional area at this station. Between Pre-Restoration Years 1 and 2, a side-bar formed on the right bank, burying the scour chain at this cross-section. The scour chain was not found during Pre-Restoration Years 3 and 4 of monitoring. In addition, the thalweg pattern changed between Pre-Restoration Years 1 and 2 so that it was no longer perpendicular to the permanently monumented cross-section markers at this location.

The first year of Post-Restoration monitoring was completed in 2017. The WC01 reach underwent an instream restoration and a new longitudinal profile and two cross-sections were selected and monitored for baseline conditions. Cross-section 1 was placed in a crossover riffle at Station 2+24, while Cross-section 2 was placed at a meander bend/pool at Station 2+71. The longitudinal profile extends 490 feet through the restored reach in Harford Glen. The survey of the longitudinal profile consisted of large riffle and pool features. During 2017, approximately 55.1% of the reach was riffle/run and 44.9% was pool/glide; in 2018, approximately 57.0% of the reach was riffle/run and 43.0% was pool/glide. During 2019, approximately 59.3% of the reach was riffle/run and 40.7% was pool/glide; in 2020, approximately 52.8% of the reach was riffle/run and 47.2% was pool/glide. The slope of the reach was high at 2.6% in 2017 and remained high at 2.7% from 2018 through 2020. The cross-sections featured stable banks exhibiting no erosion. Cross-section 1 at Station 2+24 has a defined bench and access to a small floodplain as the banks have been graded back during construction (Figure C-8). Cross-section 2 at Station 2+71 exhibits the same floodplain on the right bank in addition to a point bar, while the left bank is heavily armored by boulders (Figure C-10); between the Post-Restoration years 3 and 4 surveys, this armoring failed, resulting in several of the large boulders eroding out and falling into the stream channel, leaving the bank behind exposed to future erosion. Channel alterations were noted between the 2017 and 2018 Post-Restoration surveys. Minimal scouring (approximately 0.25 feet) of the channel at Cross-section 1 was observed, while significant aggradation of sediment was found along the right bank and channel at Cross-section 2. These changes in streambed were likely the result of an abnormally wet spring, and year overall, which shifted and transported large amounts of sediment throughout the reach. Between the 2018 and 2019 Post-Restoration surveys, channel alteration was again noted. Aggradation of approximately 1.0 feet occurred in the middle of the channel at Cross-section 1, and approximately 1.0 feet of sediment was deposited on the right bank bench was observed; significant aggradation of sediment was found along the right bank and channel at Cross-section 2. Channel alteration was again noted between the 2019 and 2020 Post-Restoration surveys. The channel was noted to have scoured between 0.5 and 0.75 feet across the majority of the channel at Cross-section 1, and approximately 0.5 feet of scouring of the bench on the right bank was observed; significant scouring of approximately 1.0 feet was found along the left and right banks, with mid-channel conditions remaining the same, at Cross-section 2. The changes in streambed were significant between 2020 and prior year surveys, likely the result of an extensive rains which shifted and transported large amounts of sediment throughout the reach. Future surveys will be useful in determining how the stream channel reacts to these changes, as well as how it stabilizes over time.

At WC01, D_{50} particle size classes remained the same between all four years of Pre-Restoration study at both cross-sections, and reachwide (Table C-3). D_{84} particle size classes changed between Years 1 and 2, coarsening at Cross-section 1 (Crossover Riffle at Station 2+29) from medium to large cobble, and becoming slightly finer at Cross-section 2 (Meander Bend at Station 2+95) from medium to small cobble. Although D_{84} classes at Cross-section 2 were unchanged between Years 2 and 3 they transformed during the fourth year of study, increasing from small cobble to medium cobble. Reachwide D_{84} particle size class fluctuated between large cobble during Year 1, to medium cobble during Year 2 and back to large cobble during Years 3 and 4.

In the first year of Post-Restoration (2017), D_{50} particle sizes decreased from very coarse gravel to medium gravel at the meander feature and from very coarse gravel to coarse gravel reachwide. In Post-Restoration Years 2 and 3, reachwide D_{50} particle sizes increased back to very coarse gravel reachwide but fluctuated between medium and very coarse gravel at the meander feature. D_{50} particle sizes categorized as coarse gravel at both the meander feature and reachwide in Post-Restoration Year 4. Riffle feature surface D_{50} particle sizes remained as very coarse gravel during all 4 years of post-restoration monitoring. In the first year of Post-Restoration monitoring (2017), reachwide D_{84} decreased to small cobble. The new crossover riffle at Station 2+24 had a D_{84} of small cobble and the new meander bend/pool at Station 2+71 had a D_{84} of very coarse gravel. In 2018, the reachwide D_{84} increased to large cobble. The crossover riffle at Station 2+24 had an increased D_{84} to large cobble and the meander bend/pool at Station 2+71 had an increased D_{84} to medium cobble. In 2019, the reachwide D_{84} decreased to small cobble. The crossover riffle at Station 2+24 had a decreased D_{84} to very coarse sand and the meander bend/pool at Station 2+71 had a decreased D_{84} to medium gravel. This overall decrease in particle size classes at WC01 was likely the result of an increase in smaller particles being transported and deposited into the reach from the above average rainfall received between 2018 and 2019. In 2020, the reachwide D_{84} increased to medium cobble. The crossover riffle at Station 2+24 had an increased D_{84} to medium cobble and the meander bend/pool at Station 2+71 had an increased D_{84} to small cobble. This overall increase in particle size classes at WC01 was likely the result of an increase in larger particles being transported and deposited into and within the reach from the above average rainfall intensities between 2019 and 2020, with enough power to redistribute larger substrate, as evidenced by the movement of the large armoring boulders at Station 2+71.

4.2 WC02

Significant changes in profile were not observed at WC02 over the four years of Pre-Restoration study. The most noticeable change is a pool feature once approximately at Station 1+00 changed to Station 0+80 (Figures C-3 and C-4). Reach length remained constant and stream slope measurements were fairly consistent overall. Feature proportions within the reach have fluctuated from year to year. While the percentage of glides increased from 0% to 16.7% between Pre-Restoration Years 1 and 2, the percentage of pools declined each year. During the fourth year (2015), 25.5% of the surveyed reach was classified as pools and glides, the lowest percentage since monitoring began. In contrast, riffles and runs made up 74.5% of the surveyed reach which was the greatest percentage of all four years (Table C-1).

Following Pre-Restoration Year 1, bed aggradation occurred at Cross-section 1 (Crossover Riffle at Station 1+38), but banks here remained relatively stable (Figure C-11). There was little change between the third and fourth year of Pre-Restoration study. Conversely, channel scour occurred at Cross-section 2 (Meander Bend at Station 3+24), as well as slight erosion of the upper portion of the right bank (Figure C-13). At this station, a bankfull bar exists along the left bank which showed little change between Pre-Restoration Years 2 and 3 of the study. However, during the fourth year of Pre-Restoration monitoring slight degradation can be seen along the left bank and bar.

In the first year of Post-Restoration monitoring, the WC02 reach consisted of 63.6% riffle/run and 36.4% pool/glide (Table C-1). This reach consisted of 60.3% riffle/run and 39.7% pool/glide in the 2018 Post-Restoration monitoring. During 2019 Post-Restoration monitoring, this reach consisted of 61.5% riffle/run and 38.5% pool/glide; the percent riffle/run and percent pool/glide was 59.0% and 41.0% during the 2020 Post-Restoration monitoring, respectively. This reach underwent instream restoration that has straightened the channel causing the meander bend cross-section to be placed in a straight pool. Overall, this reach is still somewhat lacking access to an immediate floodplain, but the banks are stable and well-vegetated despite being steep and high. The entrenchment ratio was low, 1.3, in 2017, and remained low at 1.4 in 2018 and 2019, and 1.3 in 2020, indicating the stream is confined within the banks (Appendix B). The stream is comprised predominately of long riffles and grade control steps into long/wide pools. Cross-section 1 was newly monumented in a pool at Station 0+74.5 (Figure C-12) and Cross-section 2 was monumented at Station 1+10 in a crossover riffle (Figure C-14). Both cross-sections exhibit little bank erosion and have stable banks. Cross-section 1 aggraded substantially in 2018, with more than 1.5 feet of substrate deposited in the stream channel. Significant aggradation continued in 2019, with an additional 0.5 feet of sediment deposited in the stream channel; conditions at Cross-section 1 were comparable between the 2019 and 2020 surveys. Cross-section 2 had minimal scouring (0.25 to 0.5 feet) within the channel in 2018, but experienced aggradation of 0.25 to 1.0 feet of substrate in 2019. Aggradation at this station continued in 2020, with an additional 0.25 feet of sediment being deposited. These changes in streambed could be the result of an abnormally wet years overall between 2018 and 2020, which likely shifted and transported large amounts of sediment throughout the reach. Future surveys will enable evaluation of how the stream channel reacts to these changes, as well as how it stabilizes over time.

D_{50} particle size classes remained the same between all four years of Pre-Restoration study at both cross-sections. The reachwide D_{50} for Pre-Restoration Years 2 and 3 were categorized as coarse gravel which is slightly finer than the very coarse gravel observed in Pre-Restoration Years 1 and 4 (Table C-3). D_{84} particle size classes became slightly finer at both cross-sections, diminishing from medium-sized cobble to small cobble between the first and second years of Pre-Restoration study. Furthermore, both cross-section D_{84} classes coarsened between Pre-Restoration Years 3 and 4 from small cobble to medium cobble. Although reachwide D_{84} particle sizes also reduced between Pre-Restoration Years 1 and 2, particles increased back to medium-sized cobble in Pre-Restoration Year 3 and remained during Pre-Restoration Year 4.

In the first year of Post-Restoration study (2017), D_{50} particle size classes decreased at both cross-sections and reachwide, classifying as coarse gravel at the riffle feature, very fine gravel at the meander feature, and medium gravel reachwide. Riffle feature D_{50} classification rebounded back into the very coarse gravel category in the Post-Restoration Years 2 and 3 surveys, and meander feature D_{50} particle sizes coarsened to small cobble in 2018 and medium gravel in 2019. In the Post-Restoration Year 4 survey, riffle feature D_{50} coarsened to small cobble and meander feature D_{50} coarsened to very coarse gravel. Reachwide D_{50} classifications rated as very coarse gravel in the Post-Restoration Year 4 assessment, and coarse gravel in both Post-Restoration Years 2 and 3 surveys, all coarser than the initial particle class determined by the Post-Restoration Year 1 survey, and recategorized for the first time the same as pre-restoration ratings. Reachwide D_{84} decreased to medium gravel in 2017. The new crossover riffle at Station 1+10 had a D_{84} of very coarse gravel and the new meander bend/pool at Station 0+74.5 had a D_{84} of medium gravel. In the 2018 Post-Restoration study, the reachwide D_{84} increased to coarse gravel. The crossover riffle at Station 1+10 had an increased D_{84} to medium cobble and the meander bend/pool at Station 0+74.5 had an increased D_{84} to large cobble. In the 2019 Post-Restoration study, the reachwide D_{84} increased to small cobble. The D_{84} at the crossover riffle at Station 1+10 remained as medium cobble and the meander bend/pool at Station 0+74.5 had a decreased D_{84} to small cobble. In the 2020 Post-Restoration Year 4 study, the reachwide D_{84} remained as small cobble. The D_{84} at the crossover riffle at Station 1+10 coarsened to large cobble and the meander bend/pool at Station 0+74.5 had an increased D_{84} to medium cobble.

4.3 WC03

Pool and glide features have previously dominated reach WC03, as 65.6% and 67.5% of the reach was made up of pools and glides during Pre-Restoration Years 1 and 2, respectively. During Pre-Restoration Year 3, however, riffles and runs made up more than half (53.1%) of the reach (Table C-1). Pools and glides were dominant during Pre-Restoration Year 4 (58.5%). Changes in longitudinal profile were noted between the four years' of Pre-Restoration study, most notably the deepening of most pools reachwide between the first two years (Figure C-5). Pool depth has stayed consistent from Pre-Restoration Year 2 through Year 4 except for the pool feature at station 1+00 which has deepened about a foot.

In Post-Restoration Year 1 (2017), WC03 consisted of 66.0% riffle/run and 34% pool/glide which shows a large change from Pre-Restoration Year 4 (2015) when pools and glides were dominant. These percentages were similar in subsequent surveys, with the reach consisting of 62.7% riffle/run and 37.2% pool/glide in 2018 and 62.3% riffle/run and 37.7% pool/glide in 2019. In the Post-Restoration Year 4 survey, riffle/run to pool/glide distributions transitioned closer to Pre-Restoration distributions, consisting of 50.0% riffle/run and 50.0% pool/glide. No instream restoration occurred on this reach and the stream had aggraded over time prior to 2018 (Figure C-5). Many of the pools became shallower due to this aggradation and some transitioned into riffles or runs altogether. Slight scouring was noted in this reach during the 2018 survey when compared to prior monitoring, mostly constrained to the upper 100 feet of the profile. This scouring continued in 2019 and 2020 and was evident throughout the reach instead of constrained to the upper 100 feet of the profile, likely due to above average rainfall between 2018 and 2020 which transported substrate out of the reach.

Cross-section 1 (Station 1+55) had been a crossover riffle when initially established during Pre-Restoration Year 1 of the study and again in Pre-Restoration Years 3 and 4. However, changes in channel profile resulted in the riffle feature migrating downstream, and this cross-section was within a pool feature when surveyed in Pre-Restoration Year 2 (Figure C-5). As a result, Year 2 bankfull cross-sectional dimensions changed significantly at this station, with the deepening of the channel bed (Table C-2). The Pre-Restoration Year 4 streambed most closely resembled that of the Pre-Restoration Year 2 study. The right streambank remained relatively unchanged at Cross-section 1 throughout the four-year Pre-Restoration study while the left bank slightly filled in between 2012 and 2015 (Figure C-15). Significant deepening also occurred at Cross-section 2 (Meander Bend at Station 2+07), and erosion of the outside (left) bank was also observed between Pre-Restoration Years 1 and 2 (Figure C-16). The left bank continued to erode between Pre-Restoration Years 2 and 3 while aggradation occurred in the stream bed near the left bank. Significant erosion continued on the left bank between Pre-Restoration Years 3 and 4 as well as scouring of the left bank streambed. Consequently, bankfull cross-sectional dimensions and entrenchment ratios also differed significantly at this station between all four Pre-Restoration years (Table C-2).

In the first year of Post-Restoration monitoring, Cross-section 1 at Station 1+56 continued eroding slightly on the left bank while the right bank aggraded around the toe of the bank almost 0.5 feet (Figure C-15). In 2018, the left bank stabilized, while scouring occurred around the toe of both the left and right banks. Erosion of the left bank was evident again during the 2019 survey while the toe of the left bank aggraded; measurements across the right bank demonstrated that it has remained stable. Erosion of the left bank was evident during the 2019 and 2020 surveys while the toe of the left bank aggraded in 2019 and remained similar in 2020; measurements across the right bank demonstrated that it has remained stable during Post-Restoration Years 1 through 3 surveys, but aggraded approximately 0.33 feet in the Post-Restoration Year 4 survey. Cross-section 2 at Station 2+08 has undergone major changes since Pre-Restoration Year 4 (2015). The left bank has eroded an additional 4.0 to 6.5 feet from 2015 to 2020 and has undercut the bank; the left bank at Cross-section 2 eroded away enough between 2018 and 2019 to cause the left end pin of the cross-section to fall into the stream channel, making it necessary for the field crew to install a new end pin further up the bank (Figure C-16). The streambed at this cross-section continues to scour significantly on the left side of the channel and aggrade on the right side of the channel due to the encroaching point bar.

At Cross-section 1 (crossover riffle at Station 1+55), channel substrate became finer, with the D_{50} decreasing from very coarse gravel to coarse gravel between Pre-Restoration Years 1 and 3 (Table C-3). During Pre-Restoration Year 4, D_{50} increased and was once again categorized in the very coarse gravel size class. The D_{84} decreased from small cobble to very coarse gravel and back to small cobble over the four years of Pre-Restoration monitoring. In Post-Restoration Year 1, the D_{50} decreased to coarse gravel and the D_{84} remained very coarse gravel; the Post-Restoration Year 2 D_{50} remained coarse gravel and the D_{84} increased to small cobble. In Post-Restoration Year 3, the D_{50} increased to very coarse gravel and the D_{84} increased to small cobble; the Post-Restoration Year 4 D_{50} remained very coarse gravel and the D_{84} remained small cobble.

The D_{84} decreased at Cross-section 2 (Meander Bend at Station 2+07) from small cobble in Pre-Restoration Year 1 to very coarse gravel in Pre-Restoration Years 2 and 3 to coarse gravel in Pre-Restoration Year 4. At Cross-section 2, D_{50} particle size classes remained the same between the first two years of Pre-Restoration study (medium gravel) and increased during the third (coarse gravel). During the fourth Pre-Restoration year, D_{50} size decreased from coarse gravel to fine gravel. In Post-Restoration Years 1 and 2, the D_{50} increased to medium gravel and the D_{84} increased to very coarse gravel. In Post-Restoration Year 3, the D_{50} decreased to coarse gravel and the D_{84} remained small cobble; the Post-Restoration Year 4 D_{50} decreased to medium gravel and the D_{84} decreased to very coarse gravel.

Reachwide, the D_{50} was coarse gravel during three of the four Pre-Restoration study years with a slight increase to very coarse gravel occurring in Year 3. The D_{84} showed the same pattern as the $D_{50,}$ increasing only during Pre-Restoration Year 3 to large cobble and remaining in the same small cobble class Pre-Restoration Years 1, 2, and 4. During the first Post-Restoration year (2017), the reachwide D_{50} was medium gravel and D_{84} was very coarse gravel; the reachwide D_{50} increased to coarse gravel in 2018, and D_{84} remained very coarse gravel, continuing the trend to smaller material than in years past. The reachwide D_{50} remained as coarse gravel in 2019, and D_{84} increased to small cobble, discontinuing the trend to smaller materials from years past. The reachwide D_{50} remained as coarse gravel and D_{84} remained small cobble in 2020. Future monitoring is needed to determine if the particle size distribution is stabilizing in this reach, or if continued erosion will result in shifting particle size distributions throughout this reach.

4.4 WC04

No significant changes were observed in the profile of the downstream portion of the reach at site WC04 between the four years of Pre-Restoration study. However, during Pre-Restoration Years 2 through 4 surveys and the Post-Restoration Year 1 survey, the stream channel was dry from above the pool feature at Station 1+80 to the top of the reach at Station 3+00 and beyond; the streambed was found to be mostly dry from Station 2+50 to the top of the reach in the Post-Restoration Year 2 survey. Around this same station and above, channel aggradation can be seen when comparing the profiles of the initial year and all the following years' surveys (Figure C-6) which may explain the decrease in water depth between these surveys. While no significant channel alterations were noted during the Post-Restoration Years 3 and 4 surveys, this reach was found to have water throughout the entire longitudinal profile both years; further studies are needed to determine if the increased extent of water will remain permanent at WC04 or if it was the result of above normal rainfall between 2018 and 2020 and will dry up in future years. Reach length, slope, and proportion of features within the reach remained relatively unchanged (Table C-1).

Similar to the profile, the cross-sections within this reach also remained relatively unchanged between the first three years of Pre-Restoration study, with the exception of some lower bank erosion observed at Cross-section 1 (Meander at Station 1+08) between Pre-Restoration Years 1 through 3 (Figure C-17). During Pre-Restoration Year 4, erosion on the lower left bank continued and was more apparent resulting in higher bankfull and width depth dimensions. This station was identified as a riffle located just above the top of a pool during the initial year of Pre-Restoration monitoring, but was within part of the pool when surveyed in all other subsequent Pre-Restoration years. The channel was actively widening and cutting into the bank at this station during the Pre-Restoration Year 4 survey, resulting in changes in cross-sectional dimensions. This undercutting continued to take place in Post-Restoration Years 1 through 4 (Table C-2). The overall top of bank area slightly decreased again in 2019 and remained very similar in 2020, due to the growing point bar and bench, while bankfull area slightly increased from the 2018 survey (Figure C-17). Cross-section 1 at Station 1+10 is now in a meander pool feature in Post-Restoration Years 1 through 4, a change from the original riffle feature in Pre-Restoration Year 1 and the pool feature in Pre-Restoration Years 2 through 4 (Table C-2). Cross-section 2 at Station 1+68 remains unchanged and stable through Post-Restoration Year 4, with slight aggradation occurring on the right side of the channel in Post-Restoration Years 1 and 2 (Figure C-18).

Reachwide D_{84} particle size classes remained the same during all four Pre-Restoration years (small cobble), decreased in Post-Restoration Years 1 and 2 to very coarse gravel, and increased back to small cobble in Post-Restoration Year 3 (Table C-3). D_{84} remained the same at Cross-section 1 during the first three years of Pre-Restoration study (small cobble) and decreased during the fourth year to coarse gravel, where it remained in Post-Restoration Year 1. An increase in D_{84} to very coarse gravel was noted at Cross-section 1 in 2018, and again to small cobble in 2019. D_{84} at Cross-section 1 in 2020 coarsened for a fourth straight year to medium cobble. At Cross-section 2, D_{84} decreased from small cobble to very coarse gravel between Pre-Restoration Years 2 and 3. It increased back to small cobble between Pre-Restoration Years 3 and 4 and had remained small cobble through Post-Restoration Year 2. D_{84} decreased from small cobble to coarse gravel between Post-Restoration Years 2 and 3 and increased from coarse gravel to very coarse gravel between Post-Restoration Years 3 and 4 (Table C-3).

Reachwide D_{50} particle size class increased from coarse gravel to very coarse gravel between Pre-Restoration Years 2 and 3 and decreased back to coarse gravel during Pre-Restoration Year 4 for the reachwide survey. During the Post-Restoration Year 1 survey, the reachwide D_{50} slightly decreased to medium gravel, but increased back to coarse gravel in the 2018 through 2020 studies (Table C-3). Cross-section 1 D_{50} has fluctuated by decreasing from medium gravel to very coarse sand and again increasing to medium gravel and Cross-section 2 remained the same (very coarse gravel) between Pre-Restoration Years 2, 3, and 4. In Post-Restoration Year 1, the D_{50} at Cross-section 1 remained medium gravel while the D_{50} at Cross-section 2 decreased to coarse gravel. Post-Restoration Year 2 results showed that the D_{50} at Cross-section 1 decreased again to very coarse sand while the D_{50} at Cross-section 2 increased back to very coarse gravel. Post-Restoration Year 3 results showed that the D_{50} at Cross-section 1 remained as very coarse sand while the D_{50} at Cross-section 2 decreased to coarse gravel. The Post-Restoration Year 4 assessment found the D_{50} at Cross-section 1 coarsened to very coarse gravel, while the D_{50} at Cross-section 2 remained coarse gravel (Table C-3).

5.0 CONCLUSIONS

The data presented herein provide an assessment of geomorphic conditions within the Wheel Creek watershed prior to and following completion of restoration efforts. During the Pre-Restoration Years 1 and 2 studies, none of the planned restoration projects had been completed within this watershed. During the Pre-Restoration Year 3 study, two planned restoration projects had been constructed while the remaining projects were still in planning stages. Continued planning occurred during Pre-Restoration Year 4 but no new construction activities were initiated. Restoration activities were all completed as of the Post-Restoration Year 1 survey; thus the 2020 survey is the fourth annual assessment following completion of restoration. Results of the geomorphic monitoring show that bank erosion continues to be prevalent in the two reaches (WC03, WC04) that did not receive stream restoration, but has improved in those reaches where instream channel restoration activities took place (WC01, WC02). Erosion of stream banks not only increases the sediment supply to the watershed but also provides a potential source of nutrients, especially phosphorus. Stream bank erosion is a common symptom of streams like those in Wheel Creek, where urban land cover is dominant (46.1%), contributing large amounts of impervious cover (21.4%) to the watershed (Becker, 2011). Efforts have been made to decrease the impact of damaging storm water flow causing erosion among the unstable banks. The two reaches that were restored (WC01, WC02) have stable, vegetated banks in each Post-Restoration survey and improved floodplain access in some areas but are still somewhat entrenched in others. In both restored reaches, surveyed cross-sections exhibited aggradation in the four years following completion of restoration; the undermining and failure of the bank armoring at station WC01 Cross-section 2 found in 2020 could compromise the stability of the bank and effectiveness of the restoration if not replaced. These streams may continue to adjust in the coming years, especially during high flow events. Future Post-Restoration monitoring will enable assessment of their stability and the effects of the restoration activities that occurred.

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6.0 REFERENCES

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APPENDIX A

PHOTOS

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WC01 – Facing downstream at Station 4+50

WC01 - Facing downstream at Station 3+00

WC01 – Facing downstream at Station 2+00

WC01 – Facing downstream at Station 1+00

WC01 – Facing upstream from Station 0+00

WC02 – Facing upstream at Station 3+00

WC02 – Facing upstream at Station 2+00

WC02 – Facing upstream at Station 1+00

WC02 – Facing upstream at Station 0+50

WC02 – Facing upstream at Station 0+00

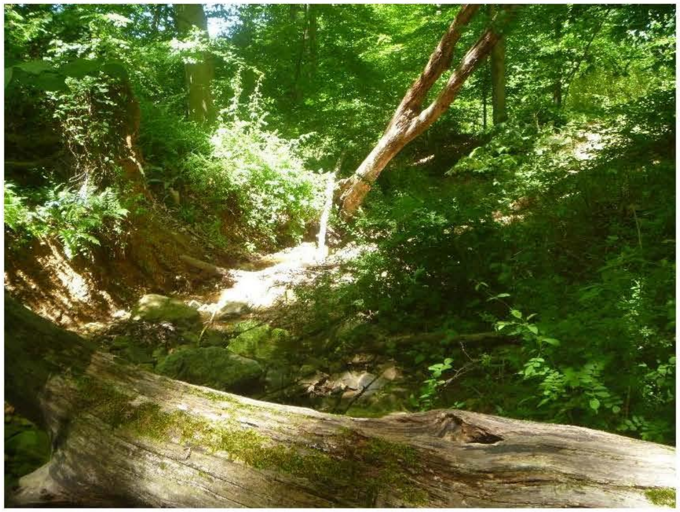
WC03 – Facing downstream at Station 3+08

WC03 – Facing downstream at Station 2+50

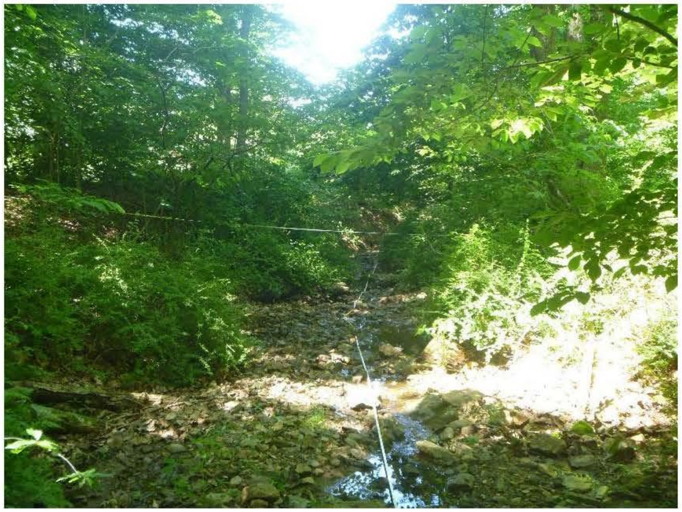
WC03 – Facing downstream at Station 1+50

WC03 – Facing downstream at Station 0+50

WC03 – Facing upstream at Station 0+00



WC04 – Facing downstream at Station 3+00



WC04 – Facing downstream at Station 2+00

WC04 – Facing downstream at Station 1+00

WC04 – Facing downstream at Station 0+50

WC04 – Facing upstream at Station 0+00

WC01 – XS-1 facing upstream

WC01 – XS-1 facing downstream

WC01 – XS-1 facing right bank

WC01 – XS-1 facing left bank

WC01 – XS-2 facing upstream

WC01 – XS-2 facing downstream

WC01 – XS-2 facing right bank

WC01 – XS-2 facing left bank

WC02 – XS-1 facing upstream

WC02 – XS-1 facing downstream

WC02 – XS-1 facing right bank

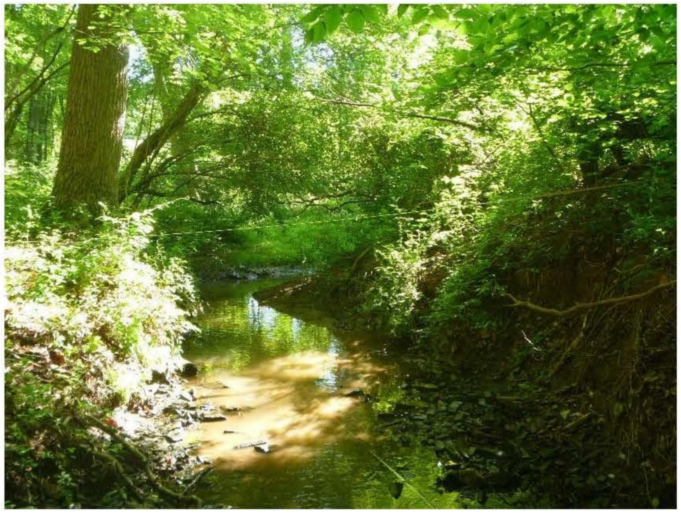
WC02 – XS-1 facing left bank

WC02 – XS-2 facing upstream

WC02 – XS-2 facing downstream

WC02 – XS-2 facing right bank

WC02 – XS-2 facing left bank



WC03 – XS-1 facing upstream

WC03 – XS-1 facing downstream

WC03 – XS-1 facing right bank

WC03 – XS-1 facing left bank


WC03 – XS-2 facing upstream


WC03 – XS-2 facing downstream


WC03 – XS-2 facing right bank


WC03 – XS-2 facing left bank

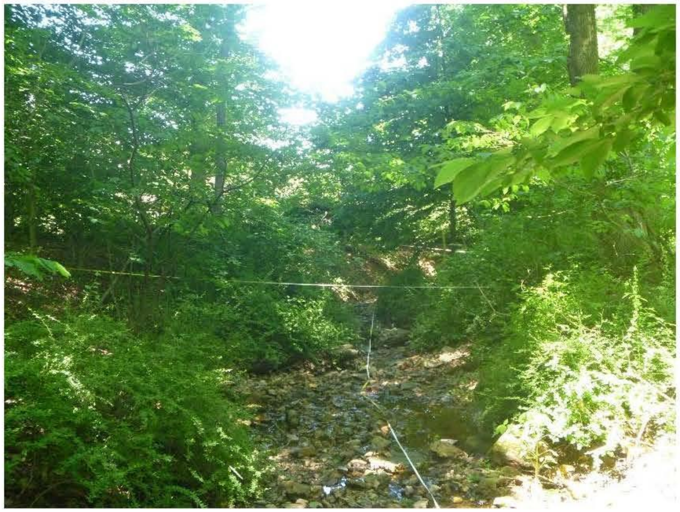
WC04 – XS-1 facing upstream

WC04 – XS-1 facing downstream

WC04 – XS-1 facing right bank

WC04 – XS-1 facing left bank

WC04 – XS-2 facing upstream



WC04 – XS-2 facing downstream

WC04– XS-2 facing right bank

WC04 – XS-2 facing left bank

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APPENDIX B

GEOMORPHIC ASSESSMENT DATA

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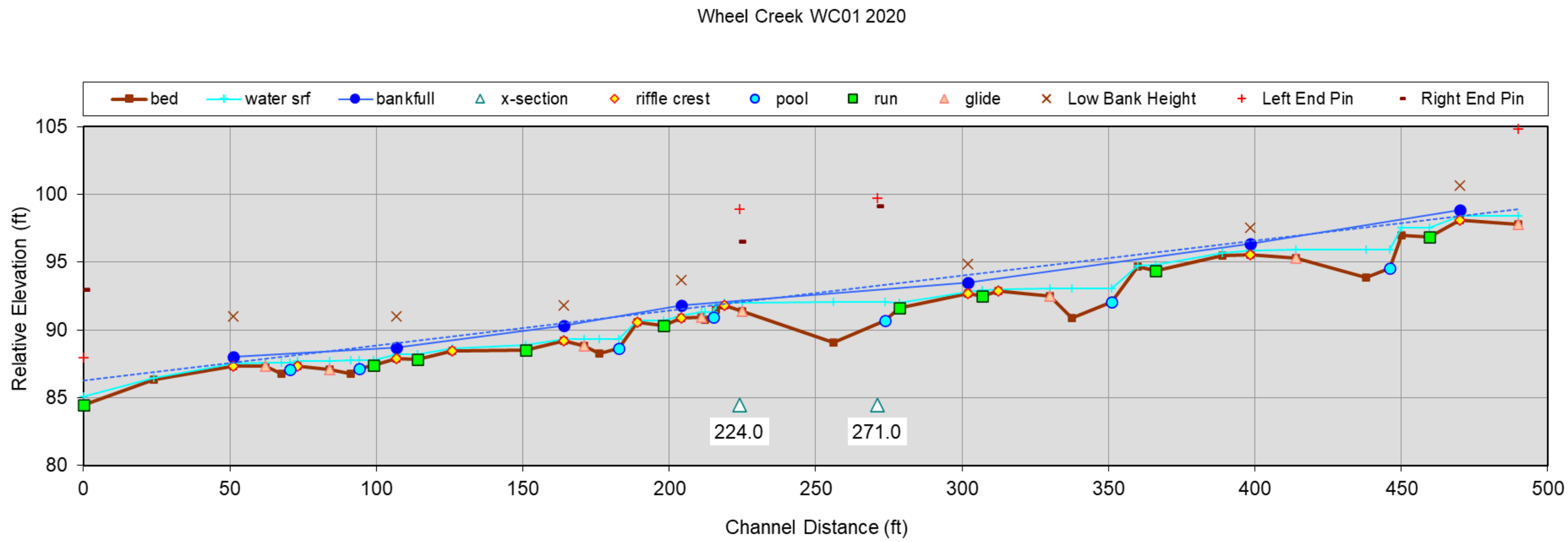
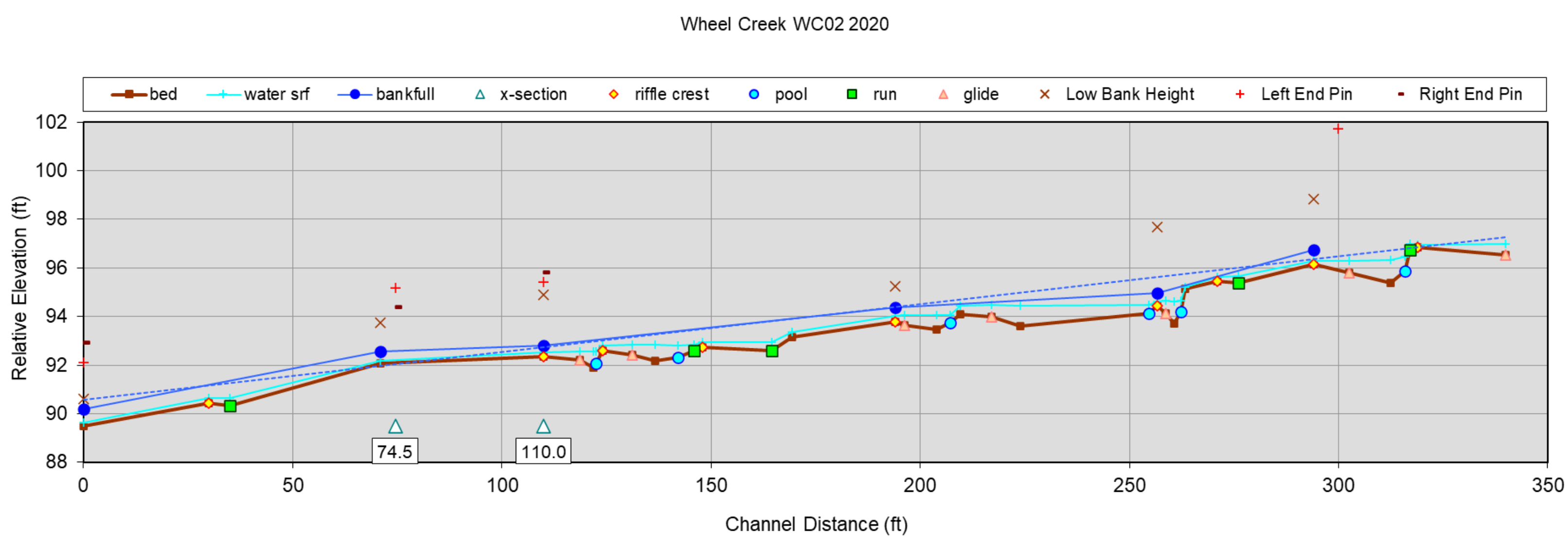
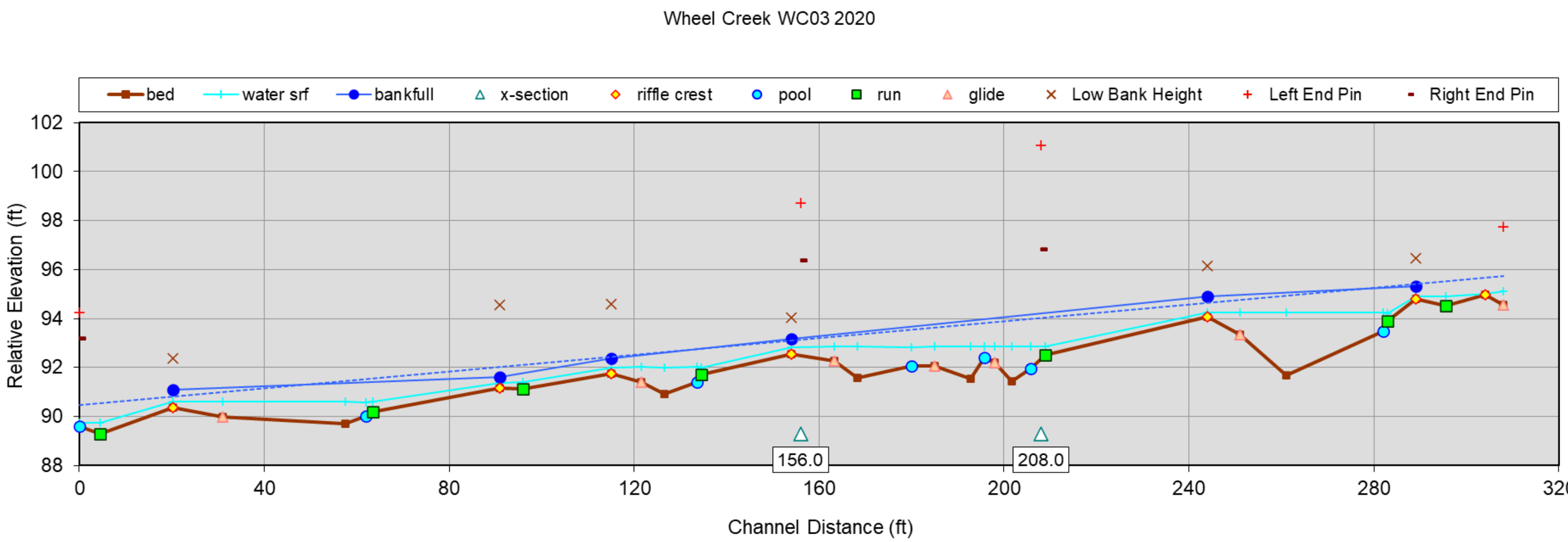
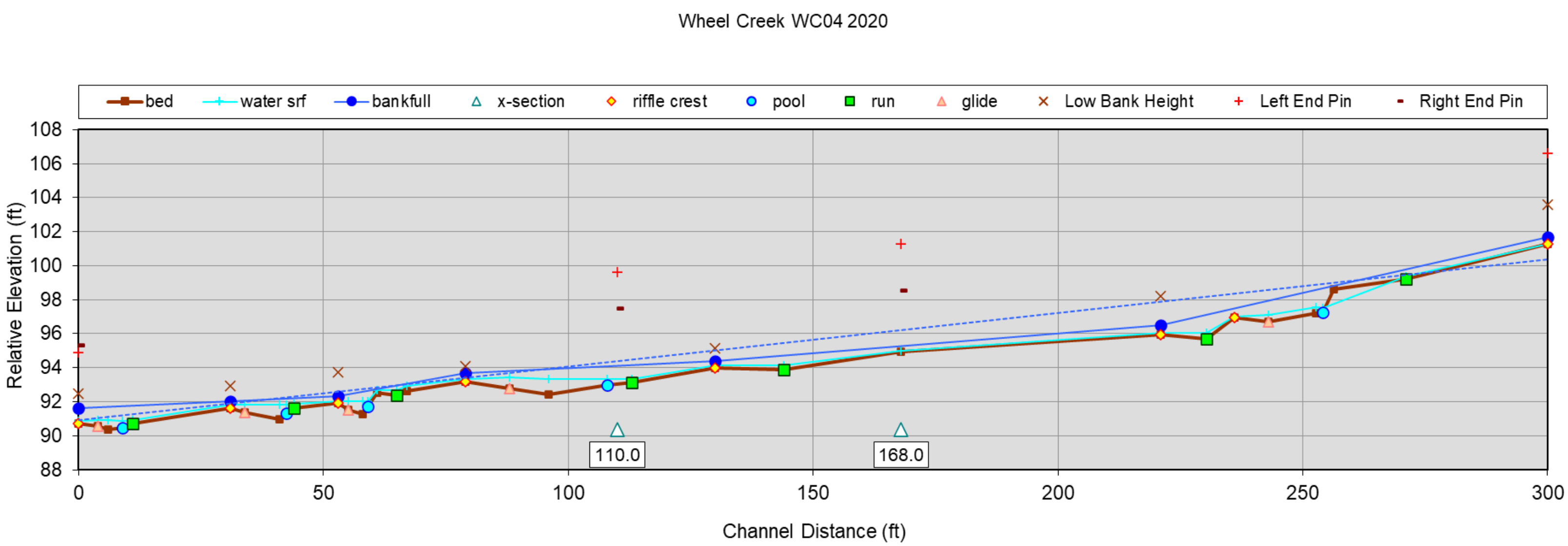

Wheel Creek WC01 2020
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
Left End Pin
Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
224.0
271.0

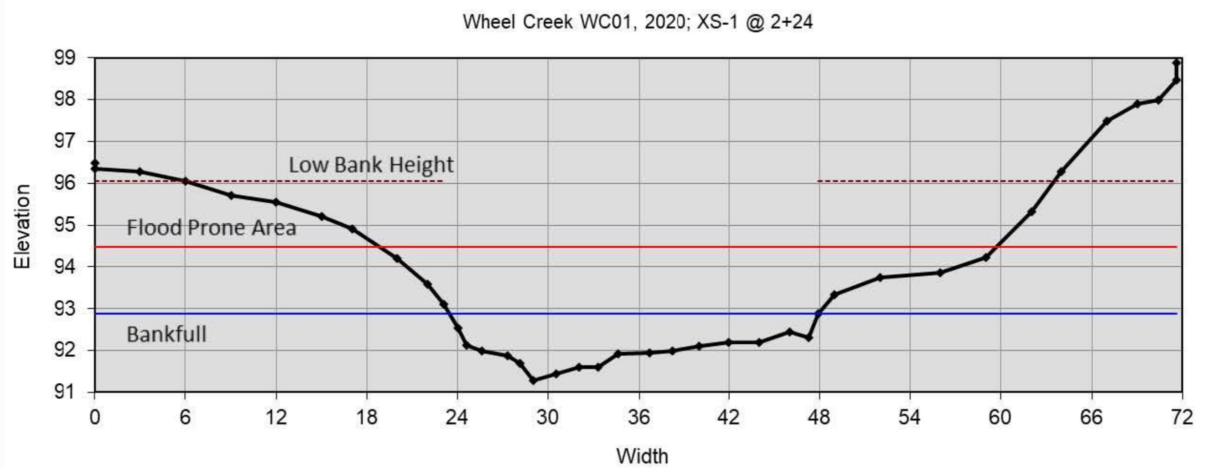

Wheel Creek WC02 2020
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
Left End Pin
Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
74.5
110.0



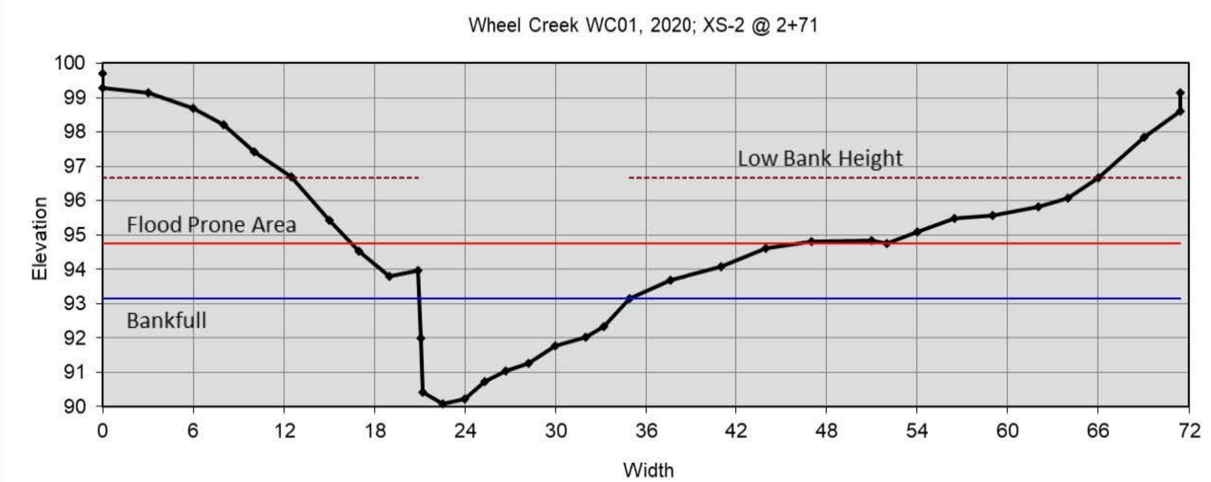
Wheel Creek WC03 2020
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
Left End Pin
Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
156.0
208.0



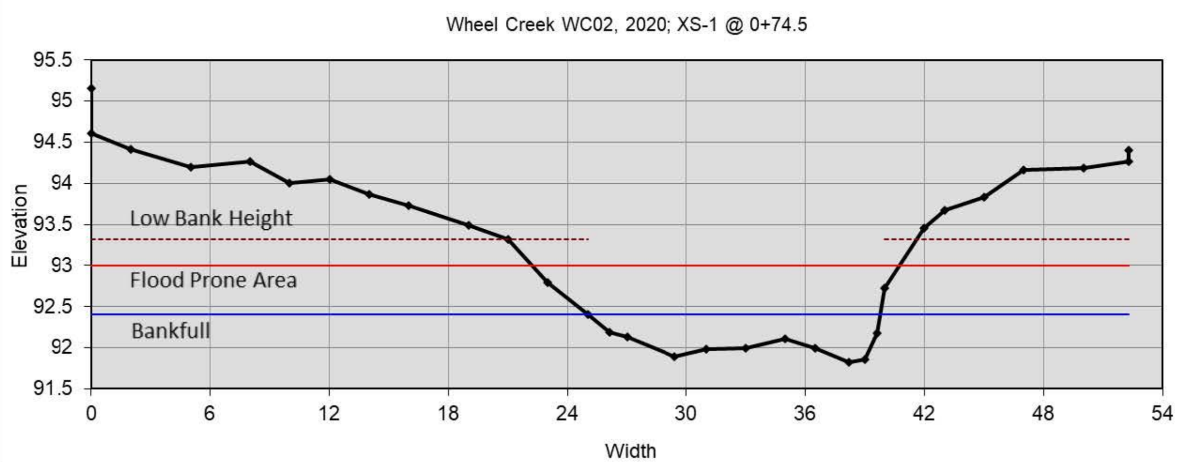
Wheel Creek WC04 2020
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
Left End Pin
Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
110.0
168.0



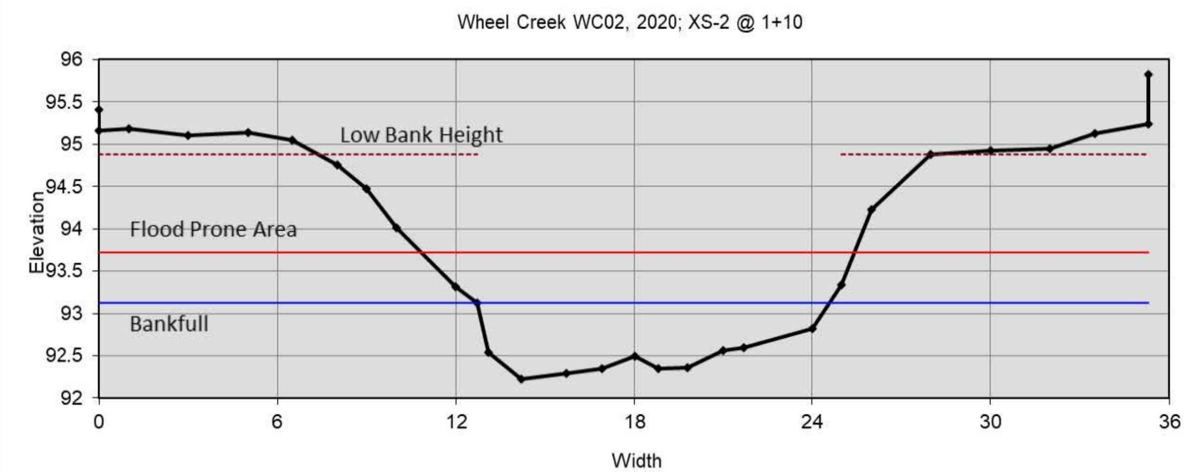
Bankfull Dimensions		Flood Dimensions		Materials	
22.1	x-section area (ft.sq.)	40.9	W flood prone area (ft)	42	D50 Riffle (mm)
24.5	width (ft)	1.7	entrenchment ratio	110	D84 Riffle (mm)
0.9	mean depth (ft)	4.8	low bank height (ft)	51	threshold grain size (mm):
1.6	max depth (ft)	3.0	low bank height ratio		
25.1	wetted parimeter (ft)				
0.9	hyd radi (ft)				
27.0	width-depth ratio				



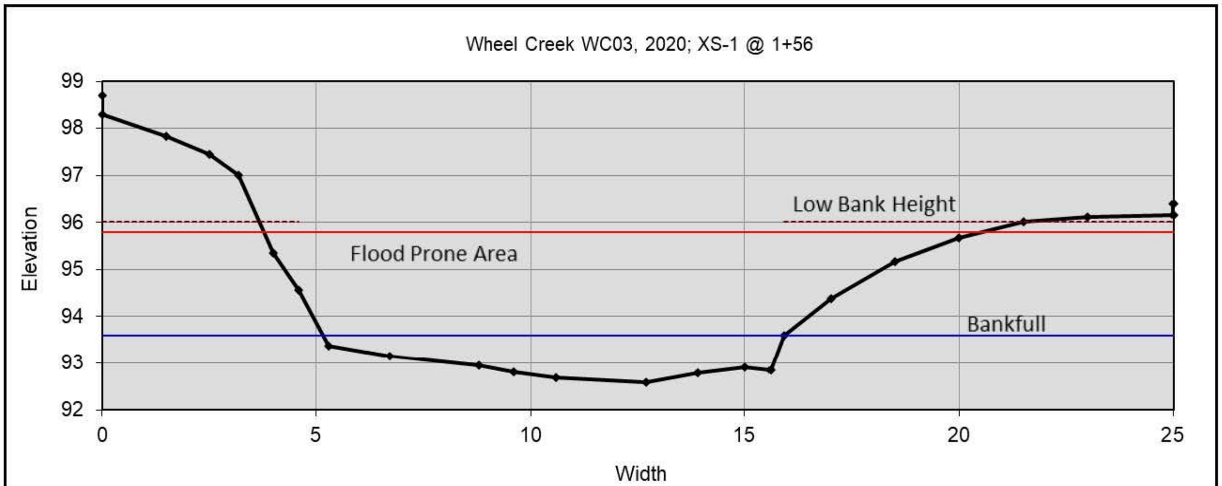
Bankfull Dimensions		Flood Dimensions		Materials	
25.4	x-section area (ft.sq.)	29.4	W flood prone area (ft)	42	D50 Riffle (mm)
13.9	width (ft)	2.1	entrenchment ratio	110	D84 Riffle (mm)
1.8	mean depth (ft)	6.6	low bank height (ft)	51	threshold grain size (mm):
3.1	max depth (ft)	2.1	low bank height ratio		
16.9	wetted parimeter (ft)				
1.5	hyd radi (ft)				
7.6	width-depth ratio				



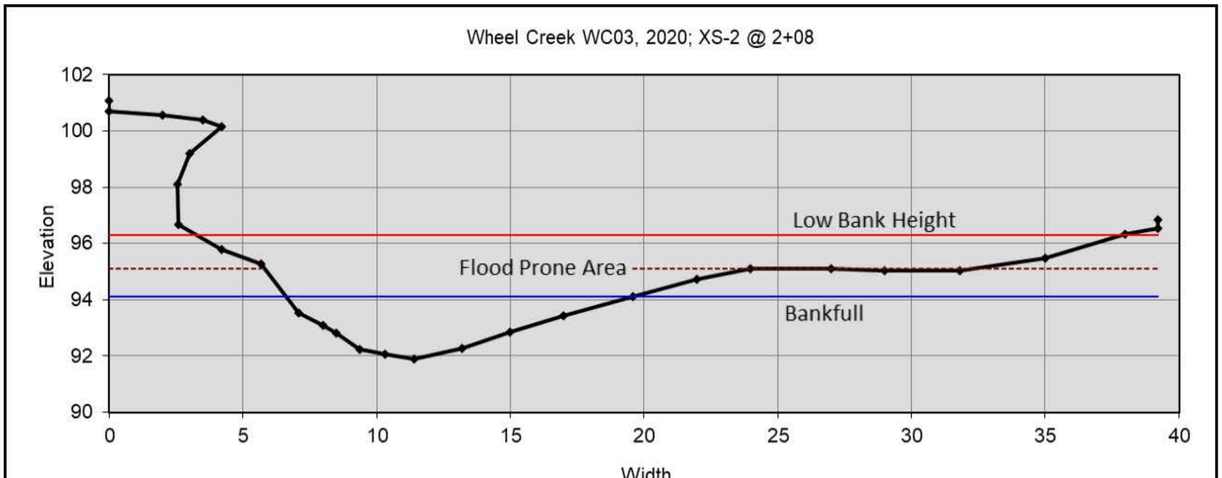
Bankfull Dimensions		Flood Dimensions		Materials	
5.7	x-section area (ft.sq.)	18.5	W flood prone area (ft)	82	D50 Riffle (mm)
14.8	width (ft)	1.3	entrenchment ratio	150	D84 Riffle (mm)
0.4	mean depth (ft)	1.5	low bank height (ft)	28	threshold grain size (mm):
0.6	max depth (ft)	2.5	low bank height ratio		
15.0	wetted parimeter (ft)				
0.4	hyd radi (ft)				
38.1	width-depth ratio				



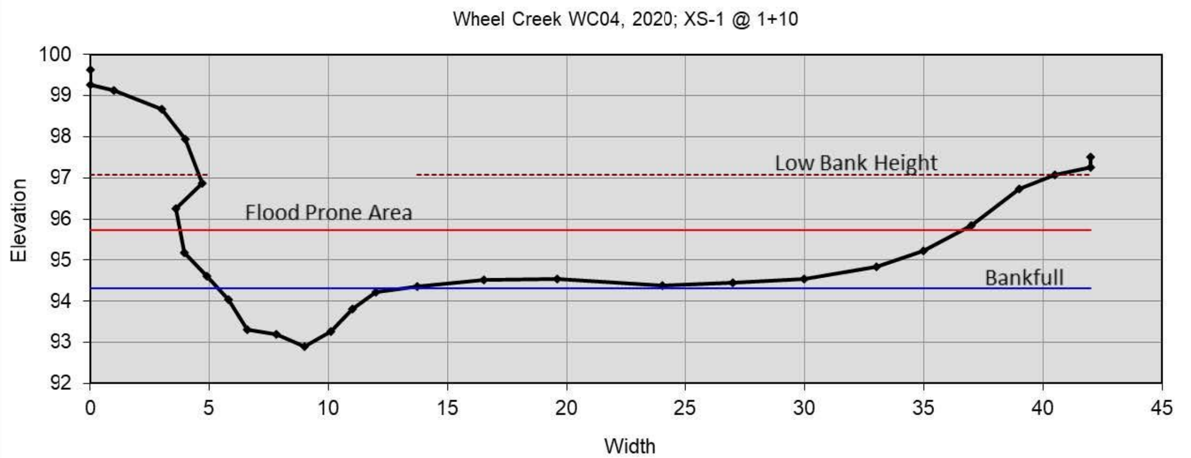
Bankfull Dimensions		Flood Dimensions		Materials	
7.6	x-section area (ft.sq.)	14.6	W flood prone area (ft)	82	D50 Riffle (mm)
11.9	width (ft)	1.2	entrenchment ratio	150	D84 Riffle (mm)
0.6	mean depth (ft)	2.7	low bank height (ft)	36	threshold grain size (mm):
0.9	max depth (ft)	2.9	low bank height ratio		
12.4	wetted parimeter (ft)				
0.6	hyd radi (ft)				
18.6	width-depth ratio				



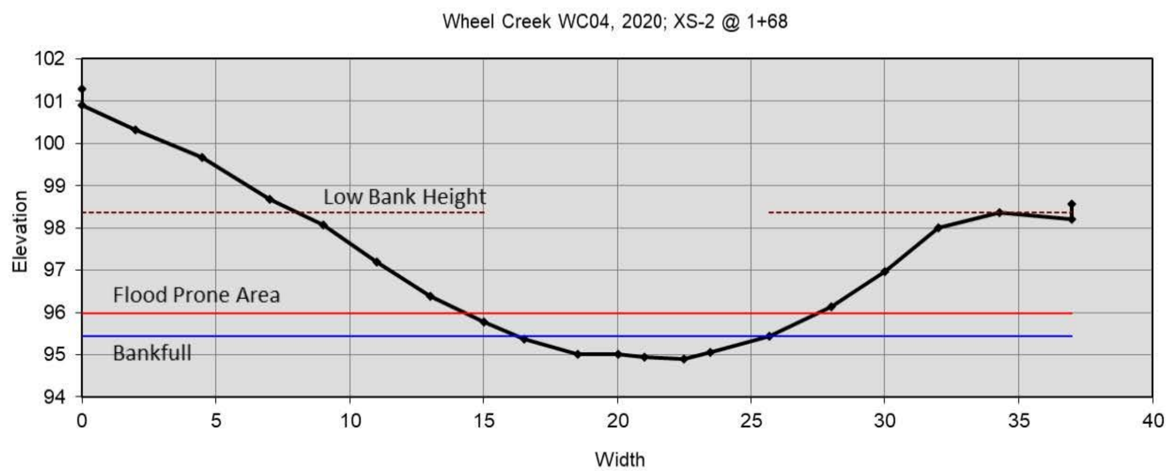
Bankfull Dimensions		Flood Dimensions		Materials	
7.6	x-section area (ft.sq.)	16.8	W flood prone area (ft)	36	D50 Riffle (mm)
10.7	width (ft)	1.6	entrenchment ratio	77	D84 Riffle (mm)
0.7	mean depth (ft)	3.4	low bank height (ft)	32	threshold grain size (mm):
1.0	max depth (ft)	3.4	low bank height ratio		
11.5	wetted parimeter (ft)				
0.7	hyd radi (ft)				
15.2	width-depth ratio				



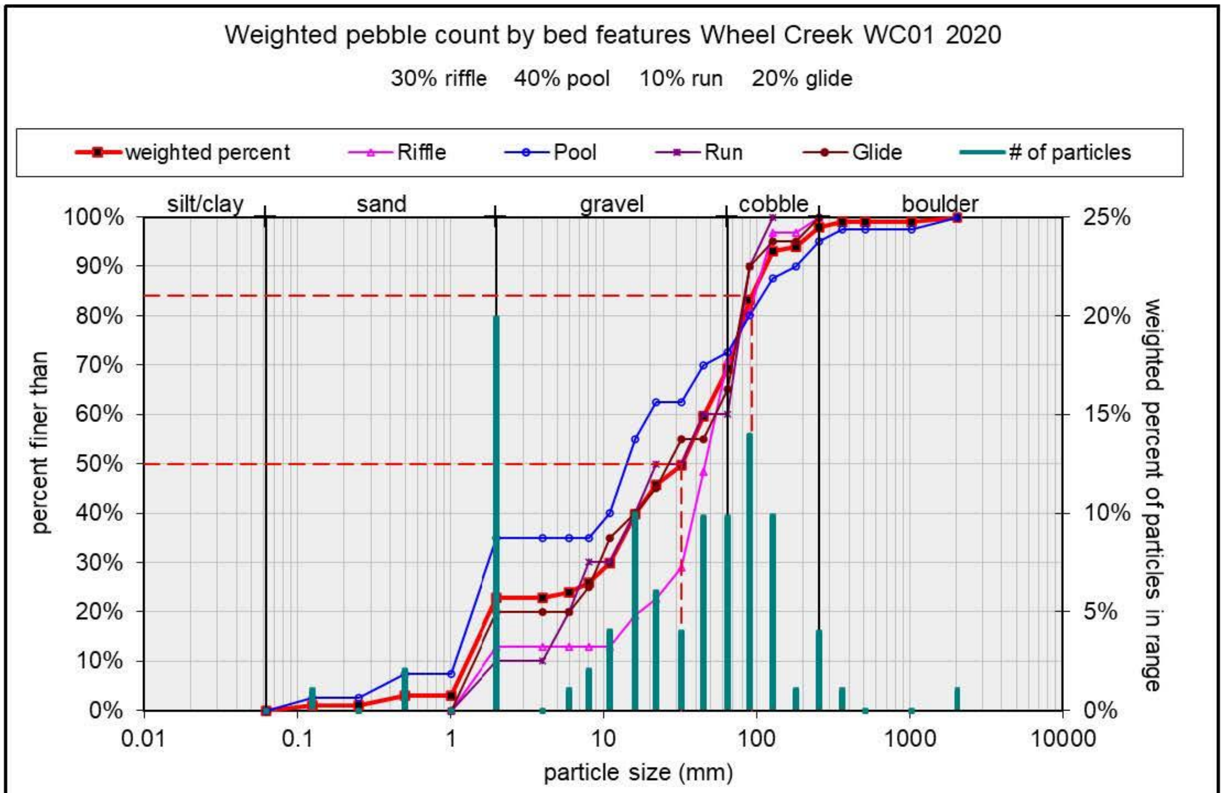
Bankfull Dimensions		Flood Dimensions		Materials	
16.2	x-section area (ft.sq.)	34.7	W flood prone area (ft)	36	D50 Riffle (mm)
13.0	width (ft)	2.7	entrenchment ratio	77	D84 Riffle (mm)
1.3	mean depth (ft)	3.2	low bank height (ft)	57	threshold grain size (mm):
2.2	max depth (ft)	1.5	low bank height ratio		
13.9	wetted parimeter (ft)				
1.2	hyd radi (ft)				
10.4	width-depth ratio				



Bankfull Dimensions		Flood Dimensions		Materials	
5.8	x-section area (ft.sq.)	32.9	W flood prone area (ft)	20	D50 Bed (mm)
7.8	width (ft)	4.2	entrenchment ratio	58	D84 Bed (mm)
0.7	mean depth (ft)	4.2	low bank height (ft)	34	threshold grain size (mm):
1.4	max depth (ft)	3.0	low bank height ratio		
8.5	wetted parimeter (ft)				
0.7	hyd radi (ft)				
10.5	width-depth ratio				



Bankfull Dimensions		Flood Dimensions		Materials	
3.3	x-section area (ft.sq.)	13.2	W flood prone area (ft)	20	D50 Bed (mm)
9.4	width (ft)	1.4	entrenchment ratio	58	D84 Bed (mm)
0.3	mean depth (ft)	3.5	low bank height (ft)	22	threshold grain size (mm):
0.5	max depth (ft)	6.4	low bank height ratio		
9.5	wetted parimeter (ft)				
0.3	hyd radi (ft)				
27.4	width-depth ratio				

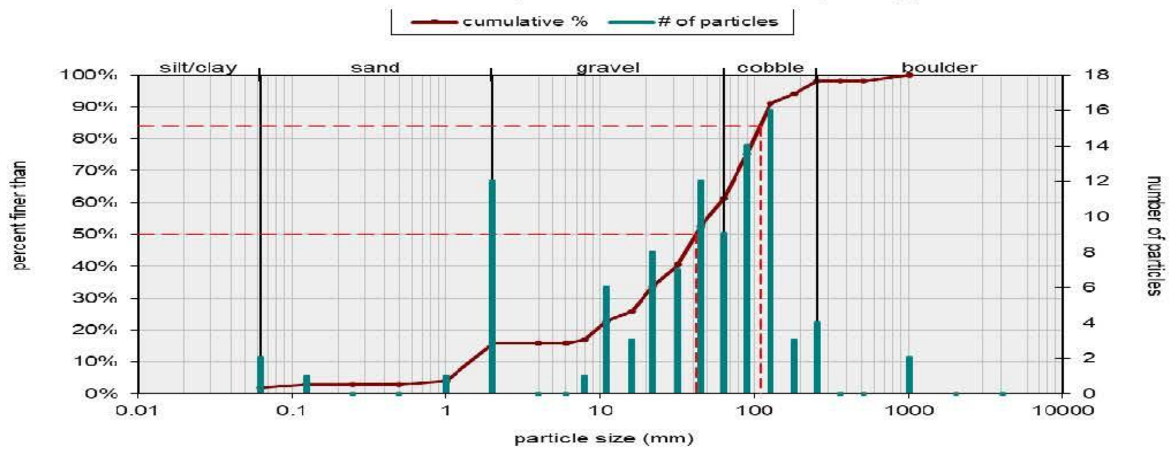


Size (mm)	
D16	1.6
D35	13
D50	32
D65	55
D84	93
D95	200

Size Distribution	
mean	12.2
dispersion	11.5
skewness	-0.32

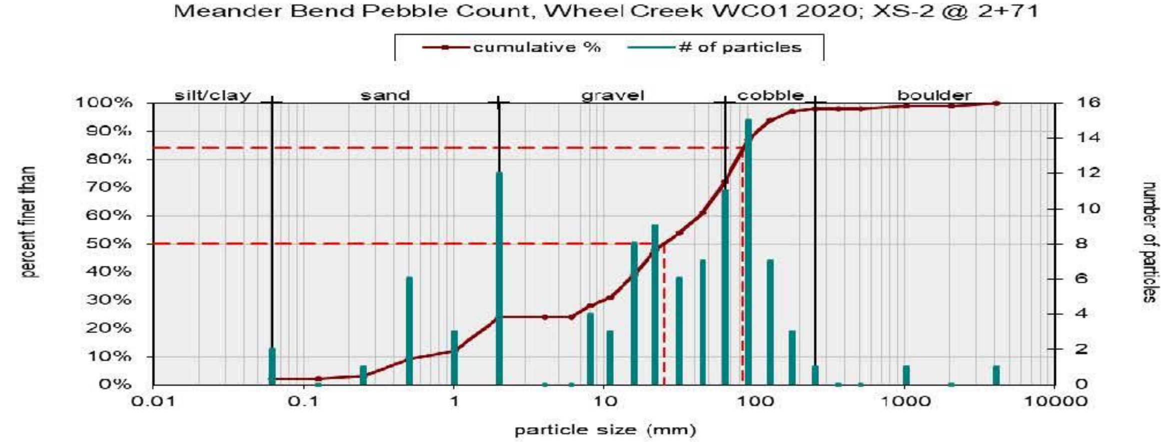
Type	
silt/clay	0%
sand	23%
gravel	46%
cobble	29%
boulder	2%

Riffle Surface Pebble Count, Wheel Creek WC01 2020; XS-1 @ 2+24

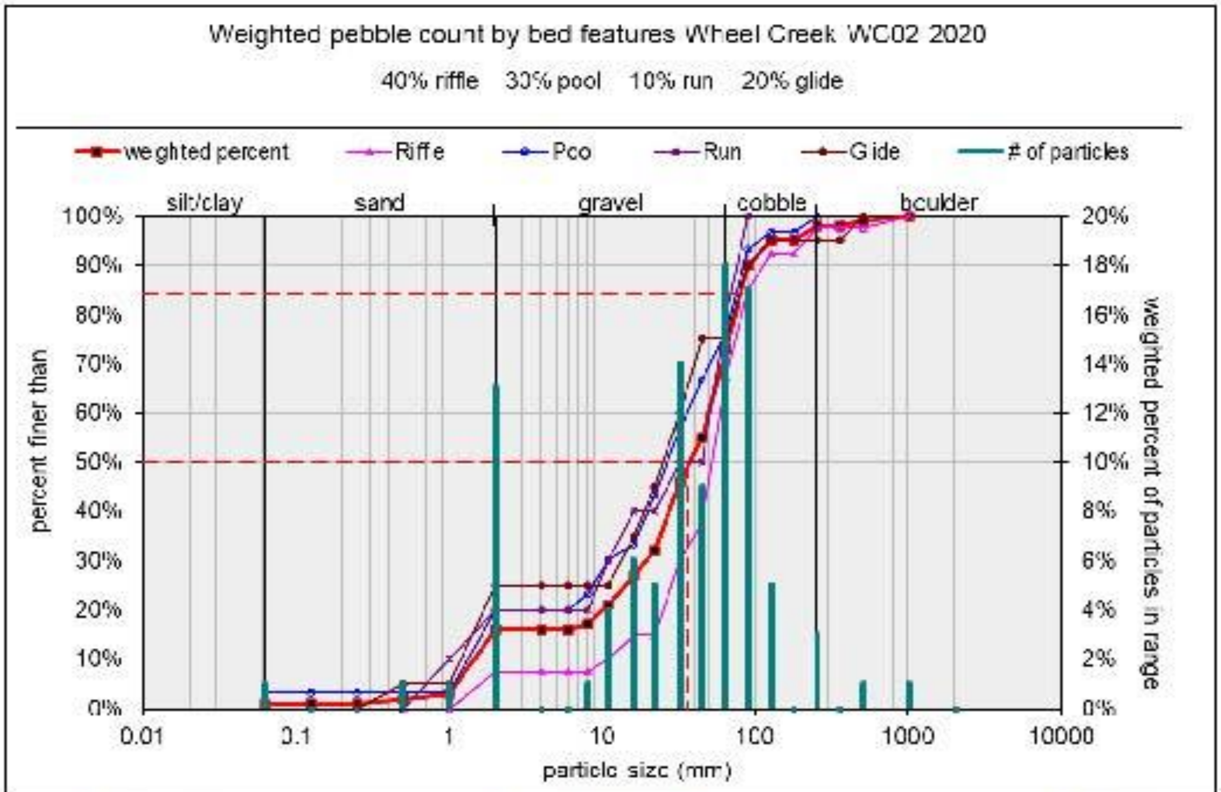


Size (mm)		Size Distribution		Type	
D16	6.3	mean	26.3	silt/clay	2%
D35	24	dispersion	4.6	sand	14%
D50	42	skewness	-0.18	gravel	46%
D65	70			cobble	37%
D84	110			boulder	2%
D95	200				

Meander Bend Pebble Count, Wheel Creek WC01 2020; XS-2 @ 2+71



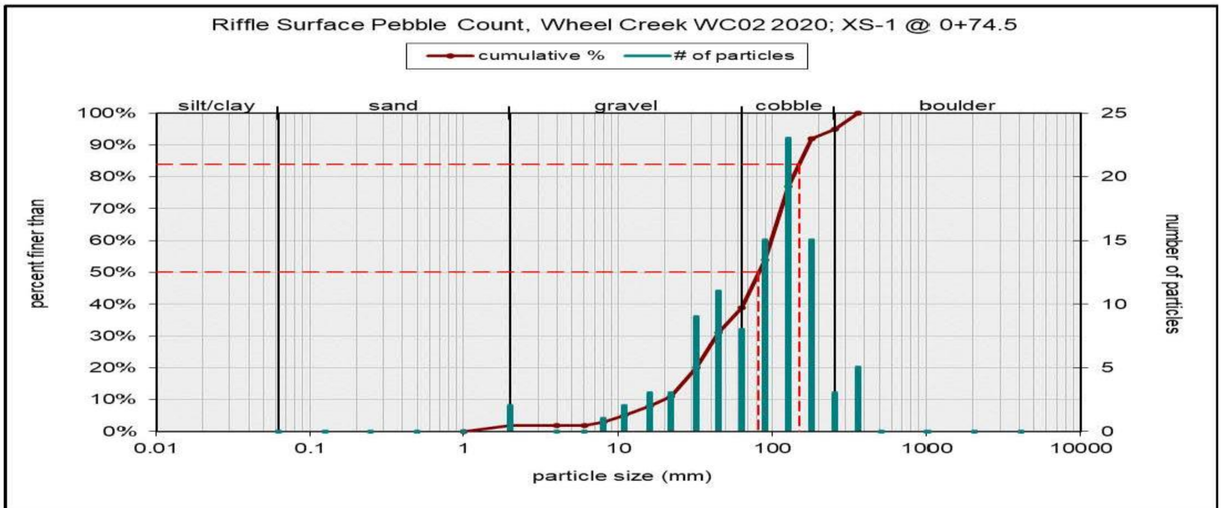
Size (mm)			Size Distribution		Type	
D16	1.3	3.4	mean	10.4	silt/clay	2%
D35	13	12	dispersion	11.3	sand	22%
D50	25	17	skewness	-0.28	gravel	48%
D65	51	20			cobble	26%
D84	84	29			boulder	2%
D95	140	39				



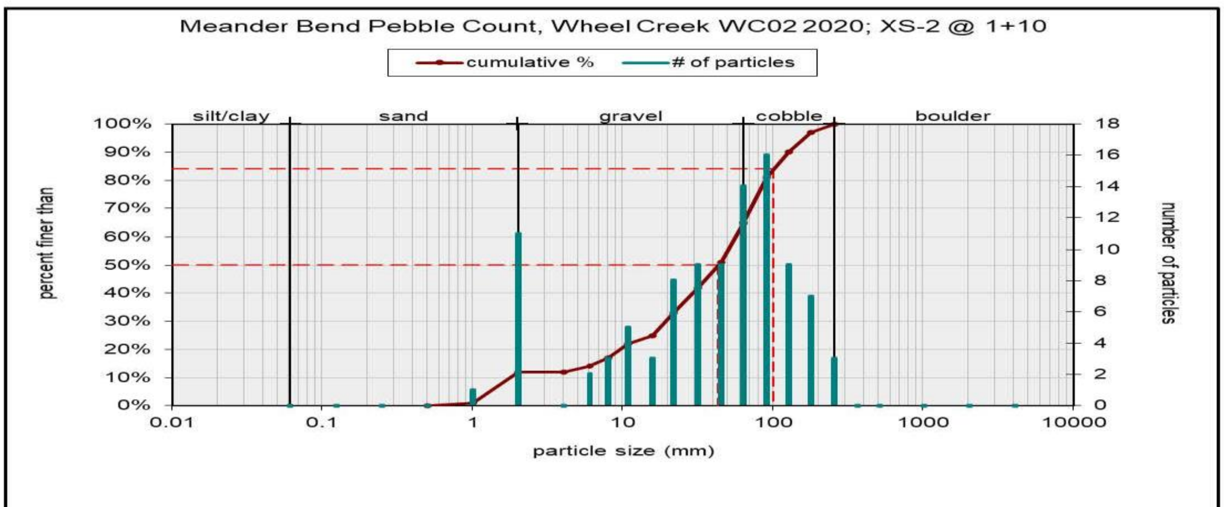
Size (mm)	
D16	6
D35	24
D50	37
D65	55
D84	80
D95	#N/A

Size Distribution	
mean	21.9
dispersion	4.2
skewness	-0.21

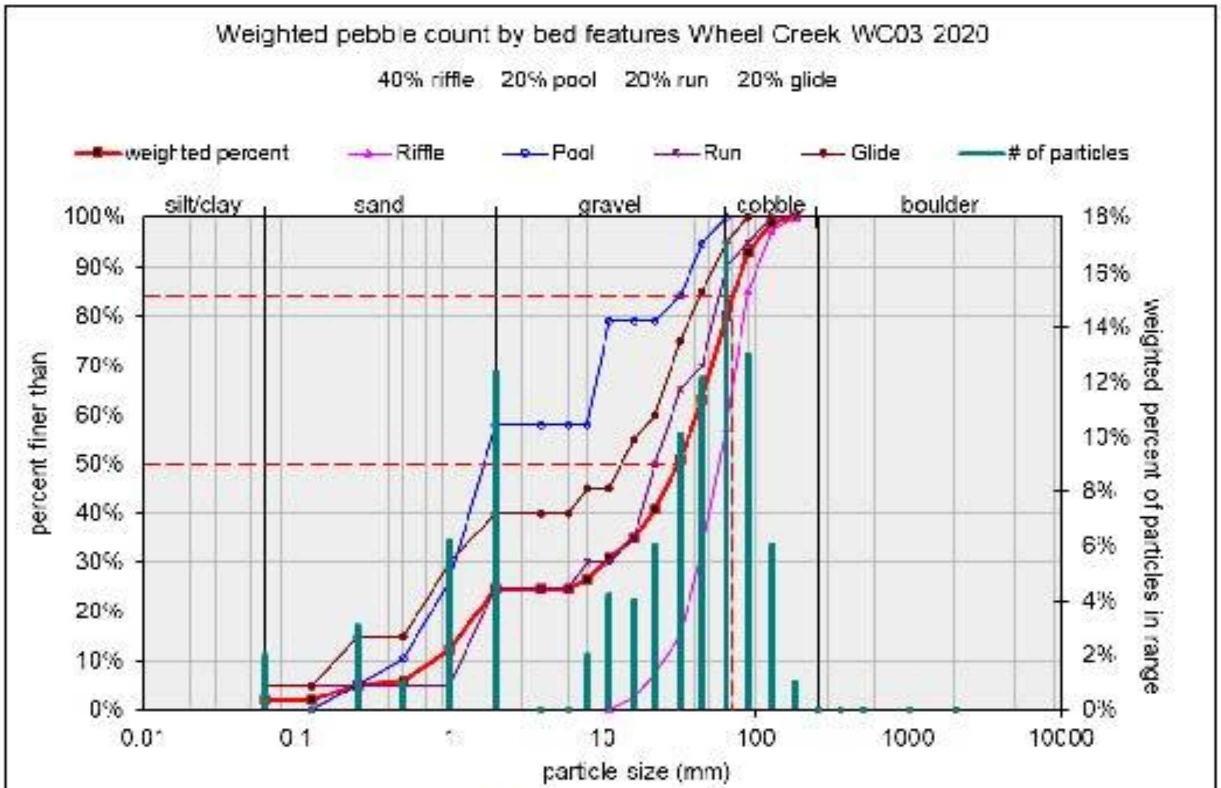
Type	
silt/clay	1%
sand	15%
gravel	57%
cobble	25%
boulder	2%



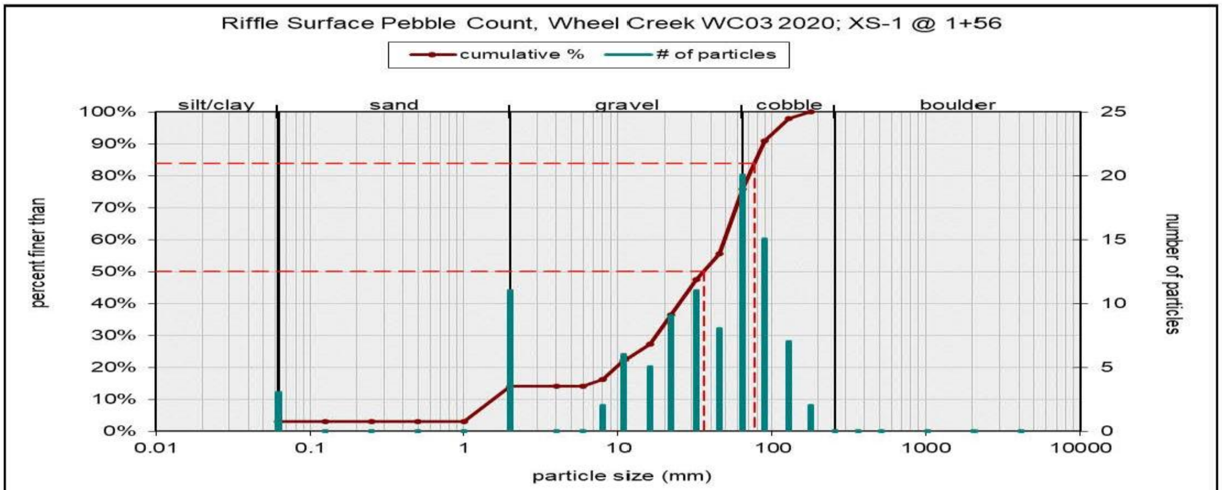
Size (mm)		Size Distribution		Type	
D16	27	mean	63.6	silt/clay	0%
D35	54	dispersion	2.4	sand	2%
D50	82	skewness	-0.13	gravel	37%
D65	110			cobble	56%
D84	150			boulder	5%
D95	260				



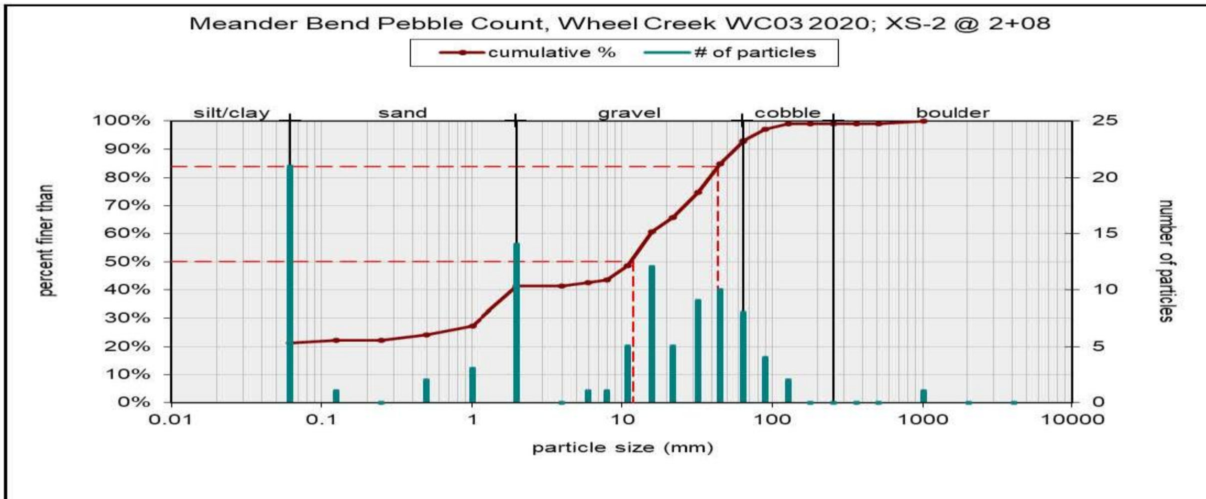
Size (mm)			Size Distribution		Type	
D16	7.3	3.4	mean	27.0	silt/clay	0%
D35	24	12	dispersion	4.1	sand	12%
D50	43	17	skewness	-0.19	gravel	53%
D65	64	20			cobble	35%
D84	100	29			boulder	0%
D95	160	39				



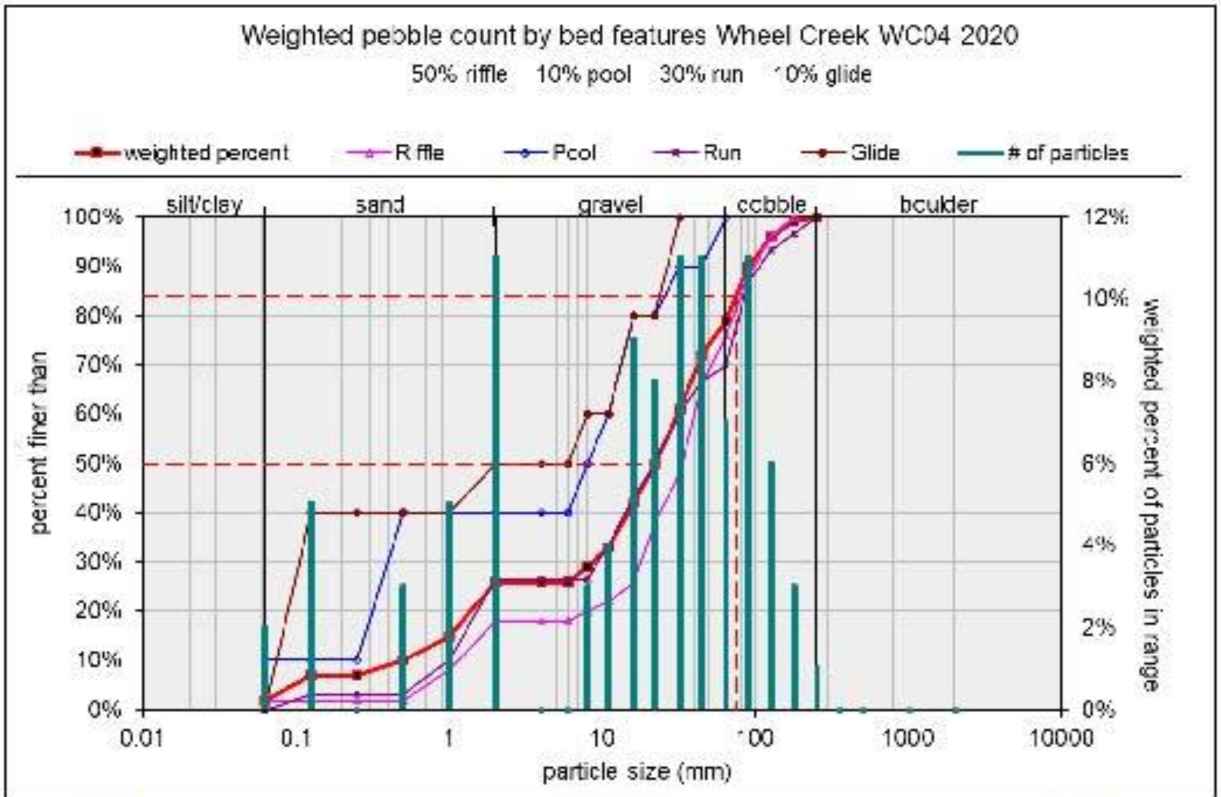
Size (mm)		Size Distribution		Type	
D16	1.2	mean	9.2	silt/clay	2%
D35	16	dispersion	14.1	sand	22%
D50	31	skewness	-0.40	gravel	54%
D65	47			cobble	20%
D84	71			boulder	0%
D95	100				



Size (mm)		Size Distribution		Type	
D16	7.8	mean	24.5	silt/clay	3%
D35	21	dispersion	3.4	sand	11%
D50	36	skewness	-0.17	gravel	61%
D65	53			cobble	24%
D84	77			boulder	0%
D95	110				



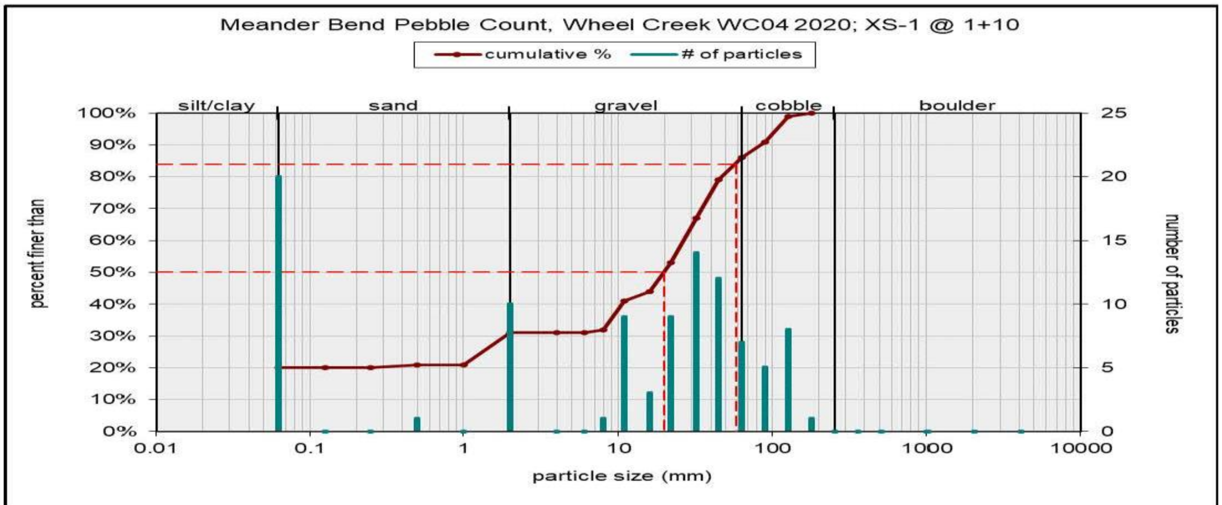
Size (mm)			Size Distribution		Type	
D16	0.062	3.4	mean	1.7	silt/clay	21%
D35	1.5	12	dispersion	98.6	sand	20%
D50	12	17	skewness	-0.51	gravel	51%
D65	21	20			cobble	6%
D84	44	29			boulder	1%
D95	76	39				



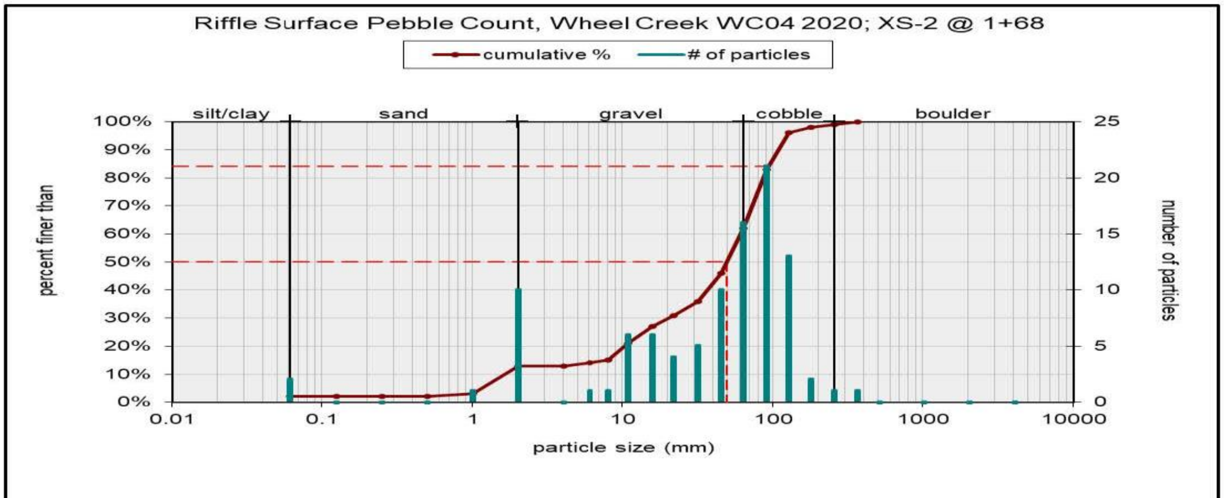
Size (mm)	
D16	1.1
D35	12
D50	22
D65	36
D84	75
D95	120

Size Distribution	
mean	9.1
dispersion	11.7
skewness	-0.28

Type	
silt/clay	2%
sand	24%
gravel	53%
cobble	21%
boulder	0%



Size (mm)		Size Distribution		Type	
D16	0.062	mean	1.9	silt/clay	20%
D35	8.9	dispersion	162.7	sand	11%
D50	20	skewness	-0.59	gravel	55%
D65	30			cobble	14%
D84	58			boulder	0%
D95	110				



Size (mm)			Size Distribution		Type	
D16	8.4	3.4	mean	27.8	silt/clay	2%
D35	30	12	dispersion	3.9	sand	11%
D50	49	17	skewness	-0.24	gravel	49%
D65	67	20			cobble	37%
D84	92	29			boulder	1%
D95	120	39				

APPENDIX C

ANNUAL COMPARISONS

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Table C-1. Comparisons of Longitudinal Profile Survey Pre-Restoration Year 1 – Year 4 (2010-2015) and Post-Restoration Years 1 – 4 (2017-2020)

Reach	**Year**	**Length (ft)**	**Slope**	**Proportion of Features**			
				Riffle	**Run**	**Pool**	**Glide**
WC01*	2010	400	2.3%	43.6%	11.3%	22.1%	23.0%
	2012	420	2.2%	54.6%	7.3%	29.2%	8.9%
	2013	420	2.2%	55.7%	8.2%	23.8%	12.3%
	2015	420	2.2%	50.9%	24.8%	14.1%	10.2%
	2017	*490*	*2.6%*	*47.5%*	*7.6%*	*36.6%*	*8.3%*
	2018	*490*	*2.7%*	*48.5%*	*8.6%*	*28.6%*	*14.4%*
	2019	*490*	*2.7%*	*46.6%*	*12.7%*	*29.4%*	*11.3%*
	2020	*490*	*2.7%*	*35.6%*	*17.2%*	*27.8%*	*19.4%*
WC02*	2010	350	2.3%	53.4%	0%	46.6%	0%
	2012	350	2.4%	33.7%	11.0%	38.6%	16.7%
	2013	350	2.3%	48.1%	12.6%	26.3%	13.0%
	2015	350	2.2%	49.4%	25.1%	13.4%	12.1%
	2017	*321.5*	*2.3%*	*57.3%*	*6.3%*	*28.5%*	*10.5%*
	2018	*320*	*2.3%*	*45.0%*	*15.3%*	*28.1%*	*11.6%*
	2019	*320*	*2.2%*	*47.6%*	*13.9%*	*26.4%*	*12.1%*
	2020	*340*	*2.2%*	*49.7%*	*9.3%*	*23.6%*	*17.4%*
WC03	2010	300	1.7%	34.4%	0%	65.6%	0%
	2012	300	1.8%	24.0%	8.5%	54.9%	12.6%
	2013	306.3	1.6%	37.2%	15.9%	30.4%	16.5%
	2015	306	1.7%	32.0%	9.5%	34.0%	24.5%
	2017	*306*	*1.7%*	*52.4%*	*13.6%*	*23.5%*	*10.5%*
	2018	*309*	*1.7%*	*48.4%*	*14.3%*	*29.4%*	*7.8%*
	2019	*308*	*1.8%*	*46.0%*	*16.3%*	*28.1%*	*9.6%*
	2020	*308*	*1.8%*	*42.6%*	*7.4%*	*35.4%*	*14.6%*
WC04	2010	300	3.5%	60.0%	0%	40.0%	0%
	2012	300	3.4%	41.3%	16.2%	30.3%	12.2%
	2013	300	3.4%	46.5%	11.0%	27.9%	14.6%
	2015	300	3.4%	50.3%	21.7%	19.0%	9.0%
	2017	*300*	*3.5%*	*48.2%*	*24.3%*	*14.0%*	*13.5%*
	2018	*300*	*3.7%*	*67.5%*	*13.0%*	*13.9%*	*5.2%*
	2019	*300*	*3.3%*	*70.0%*	*8.7%*	*13.3%*	*8.0%*
	2020	*300*	*3.5%*	*57.2%*	*18.3%*	*16.2%*	*8.3%*

*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)

Table C-2. Comparisons of Cross-sectional Survey Analyses Pre-Restoration Years 1 – 4 (2010 – 2015) and Post-Restoration Years 1 – 4 (2017 – 2020)

Reach	Year	Station	Feature	Bankfull Width (ft)	Mean Depth (ft)	Width/ Depth Ratio	Entrench-ment Ratio	Bankfull Area (ft^2)	Top of Bank Area (ft^2)
WC01*	2010	2+30	Crossover Riffle	21.1	1.0	22.2	1.5	20.1	73.0
	2012	2+30	Crossover Riffle	21.3	1.1	18.6	1.5	24.5	78.1
	2013	2+29	Crossover Riffle	21.6	1.1	20.2	1.5	23.2	66.9
	2015	2+29	Crossover Riffle	21.0	1.0	21.6	1.5	20.5	74.8
	2017	*2+24*	*Crossover Riffle*	*20.7*	*0.8*	*26.8*	*1.7*	*16.0*	*164.4*
	2018	*2+24*	*Crossover Riffle*	*21.7*	*1.0*	*21.9*	*1.8*	*21.6*	*169.6*
	2019	*2+24*	*Crossover Riffle*	*28.8*	*0.7*	*41.2*	*1.4*	*20.1*	*161.7*
	2020	*2+24*	*Crossover Riffle*	*24.5*	*0.9*	*27.0*	*1.7*	*22.1*	*148.4*
	2010	2+95	Meander/Riffle	22.1	0.8	26.0	1.5	18.8	230.1
	2012	2+95	Meander/Riffle	28.9	0.8	37.5	1.5	22.3	246.9
	2013	2+95	Meander/Riffle	29.0	0.9	34.1	1.5	24.7	212.7
	2015	2+95	Meander/Riffle	29.1	1.2	25.0	1.6	33.8	259.6
	2017	*2+71*	*Meander/Pool*	*21.3*	*2.0*	*10.7*	*1.4*	*42.6*	*269.7*
	2018	*2+71*	*Meander/Pool*	*21.5*	*1.5*	*14.5*	*1.8*	*31.8*	*236.4*
	2019	*2+71*	*Meander/Pool*	*20.3*	*1.5*	*13.5*	*2.0*	*30.6*	*223.0*
	2020	*2+71*	*Meander/Pool*	*13.9*	*1.8*	*7.6*	*2.1*	*25.4*	*144.7*
WC02*	2010	1+37	Crossover Riffle	13.1	0.7	18.4	1.2	9.3	31.6
	2012	1+38	Crossover Riffle	14.3	0.6	24.1	1.2	8.5	37.1
	2013	1+38	Crossover Riffle	14.3	0.7	19.4	1.2	10.6	36.7
	2015	1+38	Crossover Riffle	13.9	0.8	17.9	1.2	10.8	28.4
	2017	*1+10*	*Crossover Riffle*	*11.6*	*0.5*	*24.6*	*1.3*	*5.5*	*38.6*
	2018	*1+10*	*Crossover Riffle*	*13.6*	*0.7*	*20.8*	*1.4*	*8.9*	*56.5*
	2019	*1+10*	*Pool*	*12.6*	*0.7*	*17.4*	*1.3*	*9.1*	*38.4*
	2020	*1+10*	*Pool*	*11.9*	*0.6*	*18.6*	*1.2*	*7.6*	*35.3*
	2010	3+24	Meander/Riffle	16.7	0.9	19.3	1.3	14.5	70.3
	2012	3+24	Meander/Riffle	14.6	0.6	23.8	1.4	9.0	71.7
	2013	3+25.5	Meander/Riffle	15.6	0.7	21.8	1.5	11.1	72.0
	2015	3+24	Meander/Riffle	16.4	0.9	19.1	1.4	14.0	74.6
	2017	*0+74.5*	*Pool*	*13.6*	*1.3*	*10.2*	*1.3*	*18.2*	*49.0*
	2018	*0+74.5*	*Pool*	*11.6*	*0.7*	*16.5*	*1.4*	*8.1*	*43.5*
	2019	*0+74.5*	*Crossover Riffle*	*16.2*	*0.6*	*28.5*	*1.4*	*9.2*	*48.4*
	2020	*0+74.5*	*Crossover Riffle*	*14.8*	*0.4*	*38.1*	*1.3*	*5.7*	*21.8*
WC03	2010	1+55	Crossover Riffle	9.2	0.4	24.1	1.1	3.5	37.5
	2012	1+57	Pool	10.6	1.1	9.8	1.3	11.4	41.3
	2013	1+56	Crossover Riffle	10.1	0.9	11.8	1.2	8.6	38.2
	2015	1+55	Crossover Riffle	9.3	0.7	12.7	1.2	6.8	37.9
	2017	*1+56*	*Crossover Riffle*	*7.3*	*0.9*	*8.6*	*1.7*	*7.3*	*35.0*
	2018	*1+56*	*Crossover Riffle*	*10.0*	*1.1*	*9.4*	*1.3*	*10.7*	*41.6*
	2019	*1+56*	*Crossover Riffle*	*10.4*	*0.9*	*11.7*	*1.3*	*9.2*	*42.3*
	2020	*1+56*	*Crossover Riffle*	*10.7*	*0.7*	*15.2*	*1.6*	*7.6*	*40.5*
	2010	2+07	Meander/Pool	7.2	0.5	13.0	1.9	3.9	43.8
	2012	2+08	Meander/Pool	10.2	1.2	8.4	2.5	12.5	56.2
	2013	2+12	Meander/Pool	9.7	1.0	10.0	2.7	9.4	55.0
	2015	2+07	Meander/Pool	9.9	1.1	9.4	2.8	10.5	61.4
	2017	*2+08*	*Meander/Run*	*9.8*	*0.9*	*12.2*	*2.7*	*9.8*	*61.5*
	2018	*2+08*	*Meander/Run*	*11.5*	*0.6*	*18.3*	*2.3*	*7.2*	*61.8*

Table C-2. (Continued)									
Reach	**Year**	**Station**	**Feature**	**Bankfull Width (ft)**	**Mean Depth (ft)**	**Width/ Depth Ratio**	**Entrench-ment Ratio**	**Bankfull Area (ft^2)**	**Top of Bank Area (ft^2)**
WC03	*2019*	*2+08*	*Meander/Run*	*11.6*	*0.7*	*15.9*	*1.6*	*8.5*	*62.6*
	2020	*2+08*	*Meander/Run*	13.0	1.3	*10.4*	*2.7*	*16.2*	*32.1*
WC04	2010	1+08	Meander/Riffle	4.3	0.4	9.8	4.3	1.9	92.5
	2012	1+08	Meander/Pool	6.7	0.6	11.4	3.9	4.0	95.9
	2013	1+08	Meander/Pool	13.0	0.6	23.5	2.2	7.2	99.9
	2015	1+08	Meander/Pool	13.6	0.6	24.0	2.3	7.7	102.8
	2017	*1+10*	*Meander/Pool*	*20.6*	*0.4*	*51.3*	*1.5*	*8.3*	*99.8*
	2018	*1+10*	*Meander/Pool*	*6.8*	*0.6*	*13.6*	*3.4*	*4.5*	*93.4*
	2019	*1+10*	*Meander/Pool*	*11.6*	*0.4*	*28.8*	*2.7*	*4.7*	*90.7*
	2020	*1+10*	*Meander/Pool*	*7.8*	*0.7*	10.5	4.2	5.8	*90.9*
	2010	1+68	Crossover Riffle	8.9	0.4	24.0	1.4	3.3	55.9
	2012	1+68	Crossover Riffle	9.2	0.5	18.9	1.5	4.4	57.8
	2013	1+68	Crossover Riffle	10.4	0.5	20.4	1.4	5.3	56.3
	2015	1+68	Crossover Riffle	11.1	0.6	17.4	1.6	7.1	55.6
	2017	*1+68*	*Crossover Riffle*	*10.4*	*0.5*	*22.3*	*1.4*	*4.8*	*54.8*
	2018	*1+68*	*Crossover Riffle*	*9.2*	*0.3*	*28.8*	*1.3*	*3.0*	*55.4*
	2019	*1+68*	*Crossover Riffle*	*9.7*	*0.4*	*24.1*	*1.4*	*3.9*	*56.0*
	2020	*1+68*	*Crossover Riffle*	*9.4*	*0.3*	*27.4*	*1.4*	*3.3*	*55.7*
*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)									

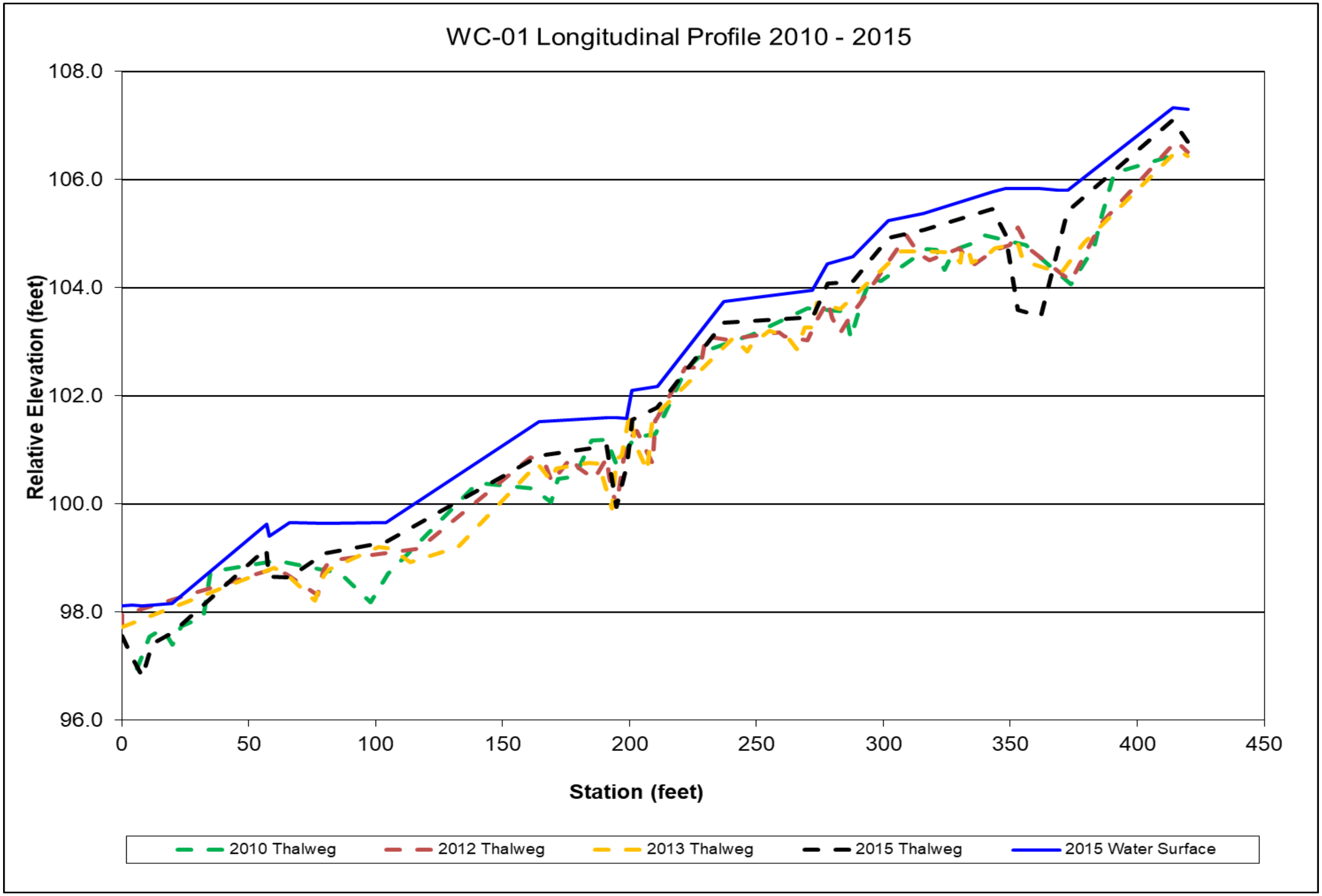

Figure C-1. WC-01 Longitudinal Profile (Pre-Restoration)

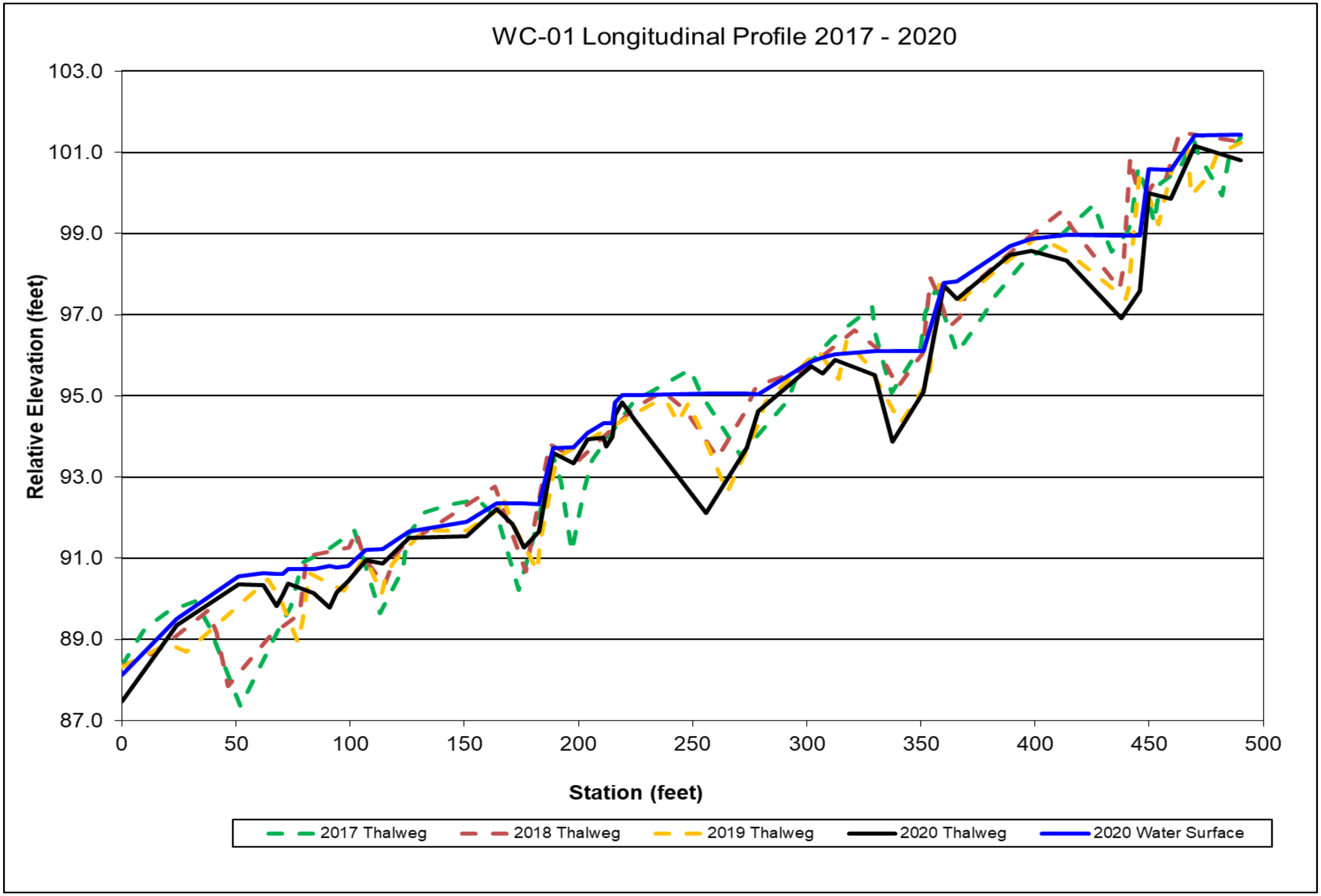

Figure C-2. WC-01 Longitudinal Profile (Post-Restoration)

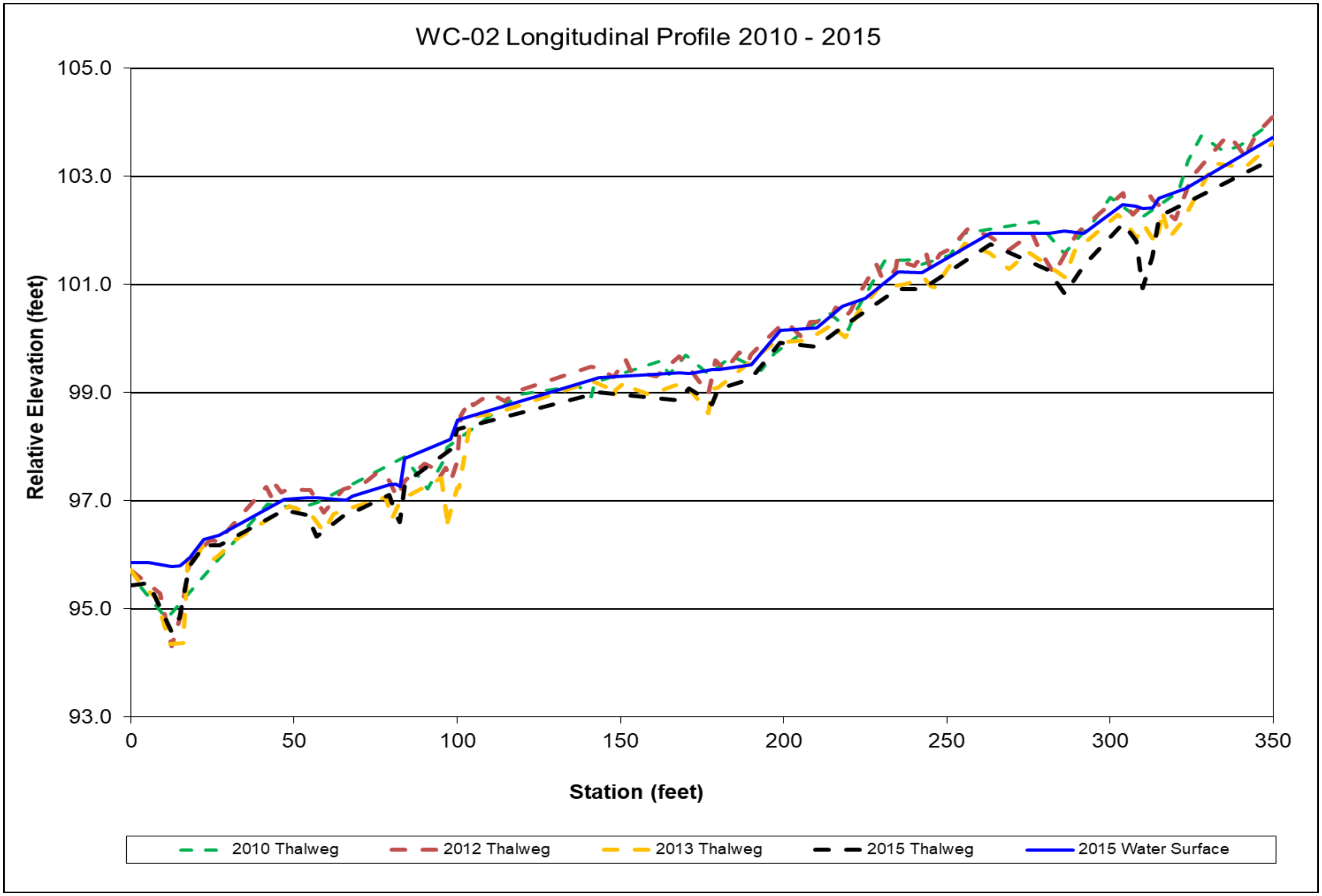

Figure C-3. WC-02 Longitudinal Profile (Pre-Restoration)

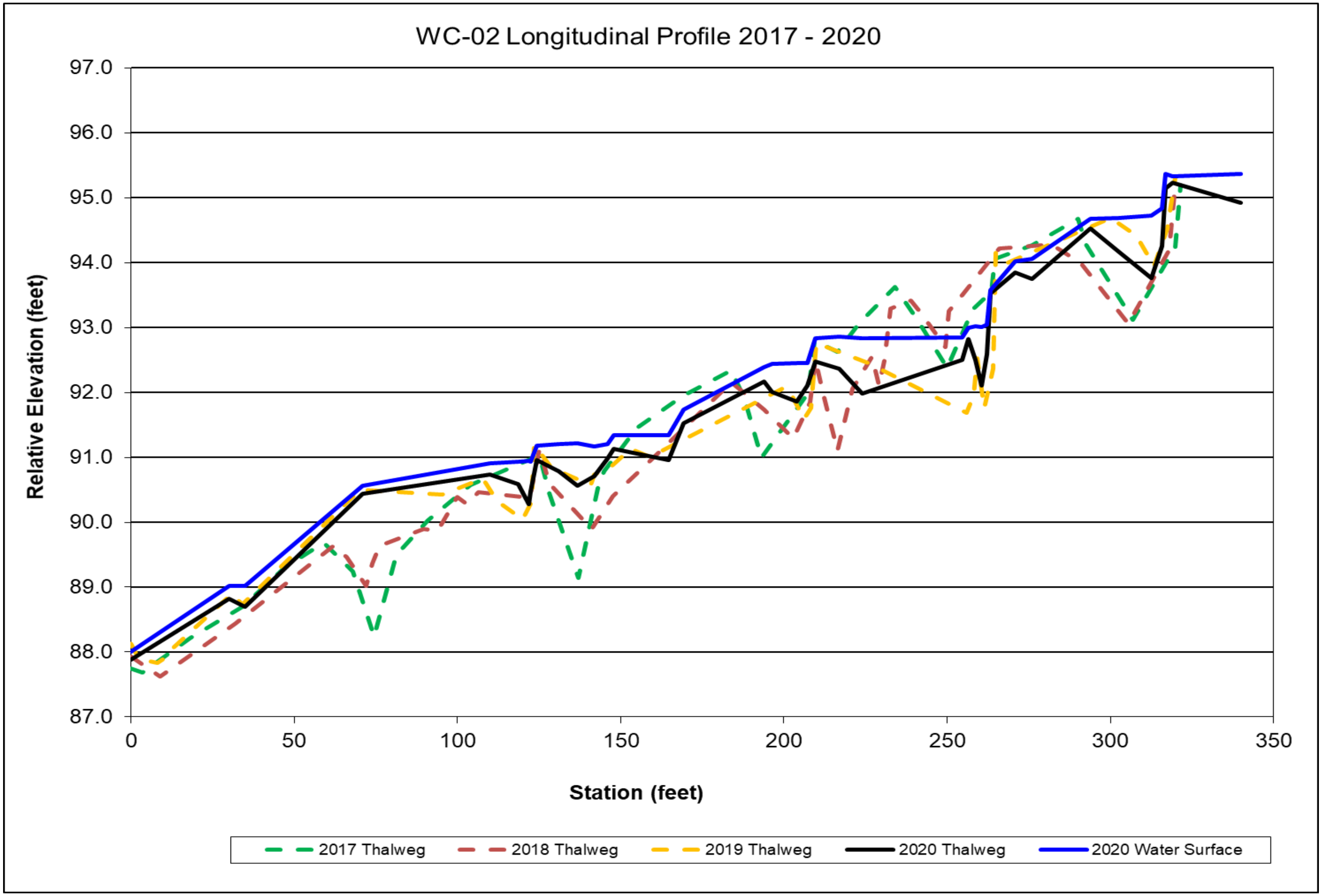

Figure C-4. WC-02 Longitudinal Profile (Post-Restoration)

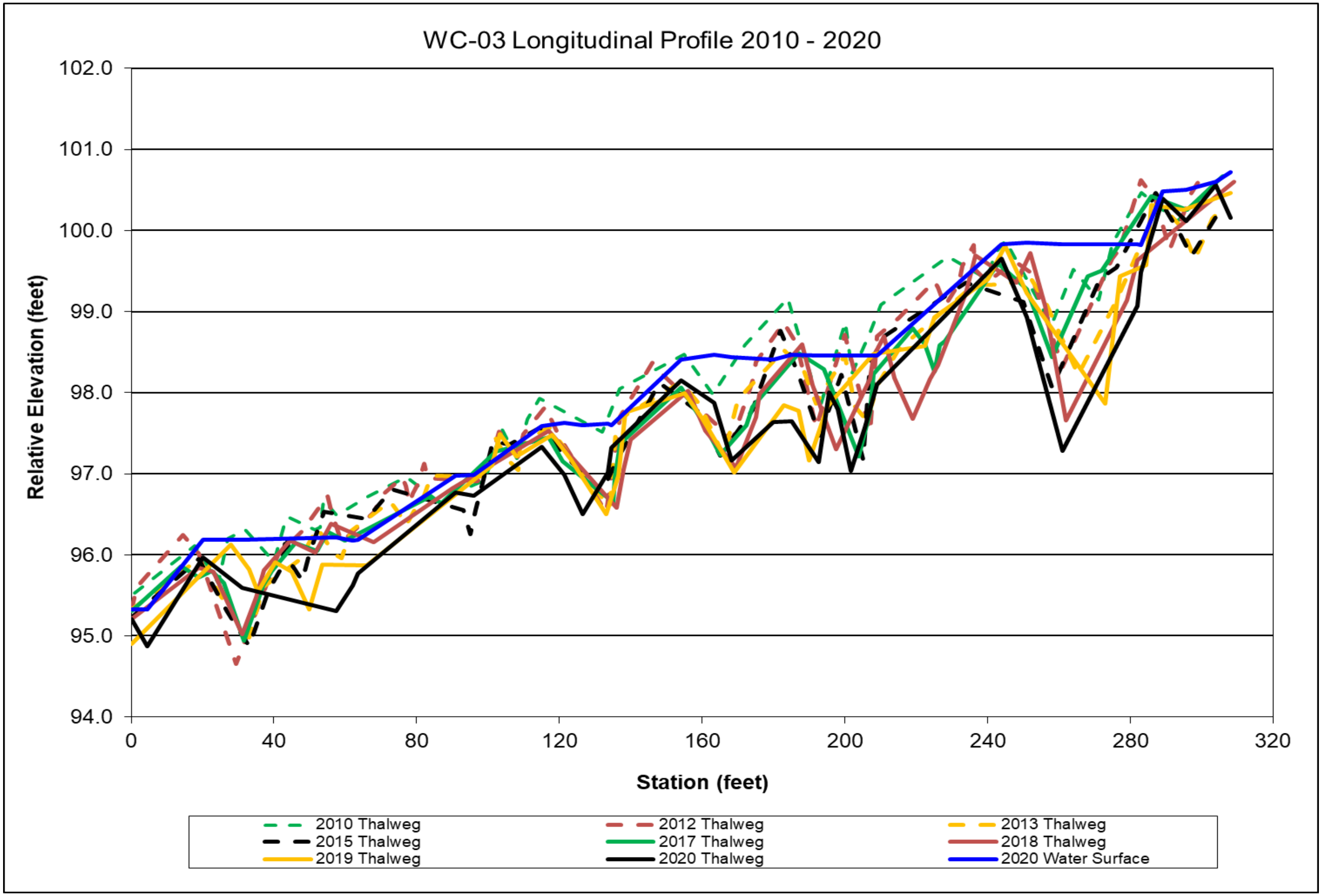

Figure C-5. WC-03 Longitudinal Profile (Pre- and Post-Restoration)

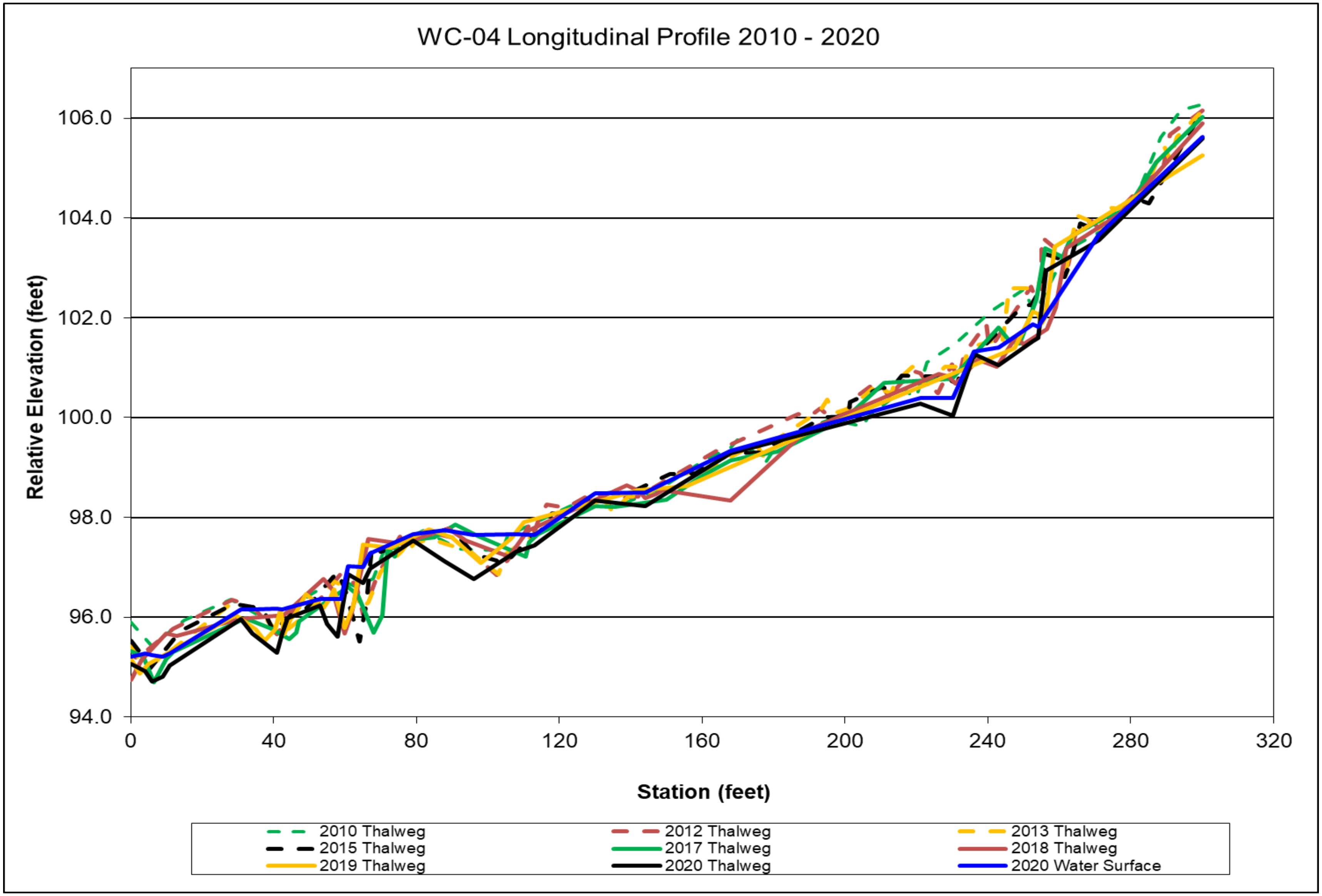

Figure C-6. WC-04 Longitudinal Profile (Pre- and Post-Restoration)

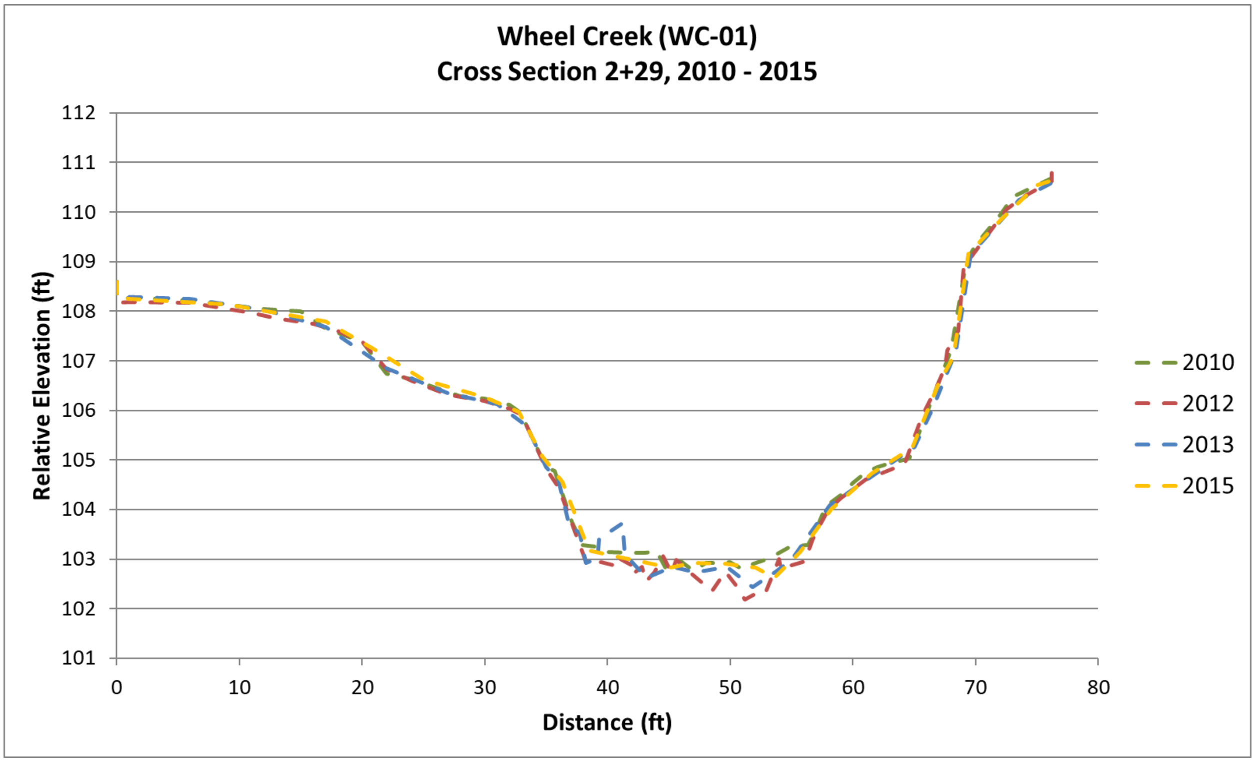

Figure C-7. WC01 Cross-section 1 (Pre-Restoration)

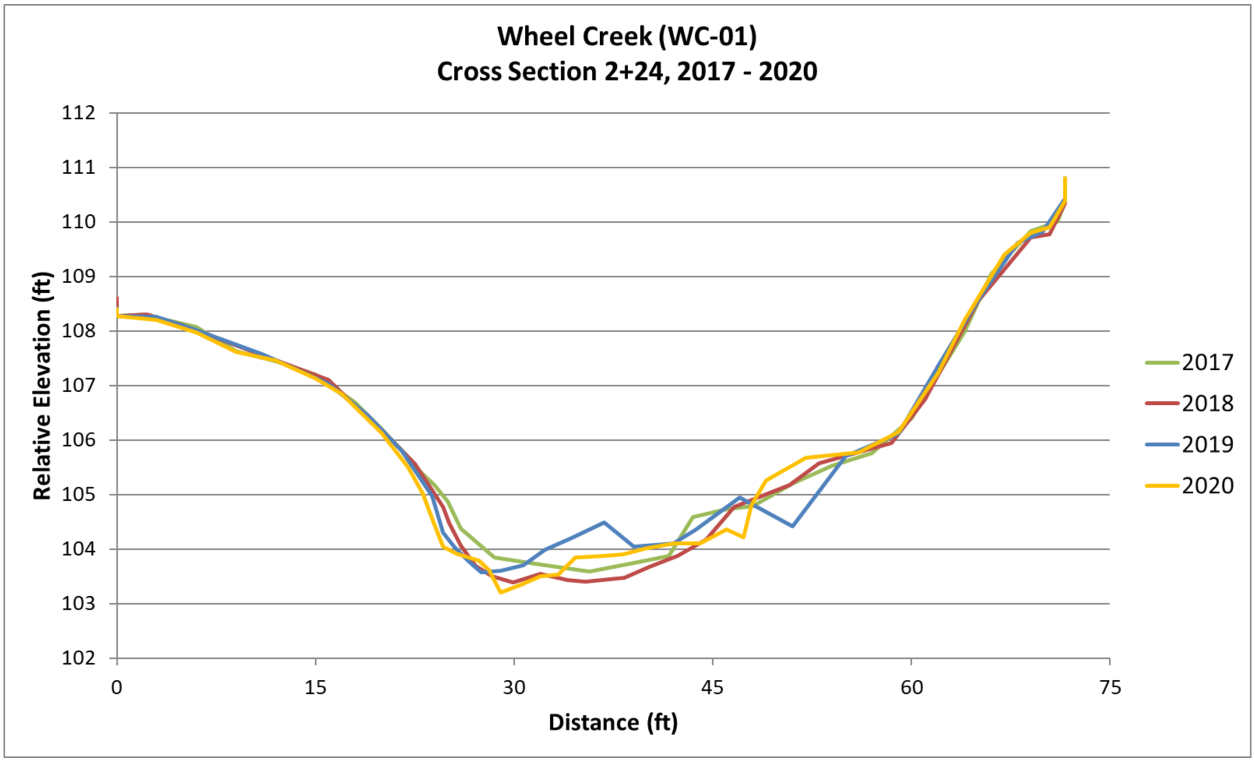

Figure C-8. WC01 Cross-section 1 (Post-Restoration)

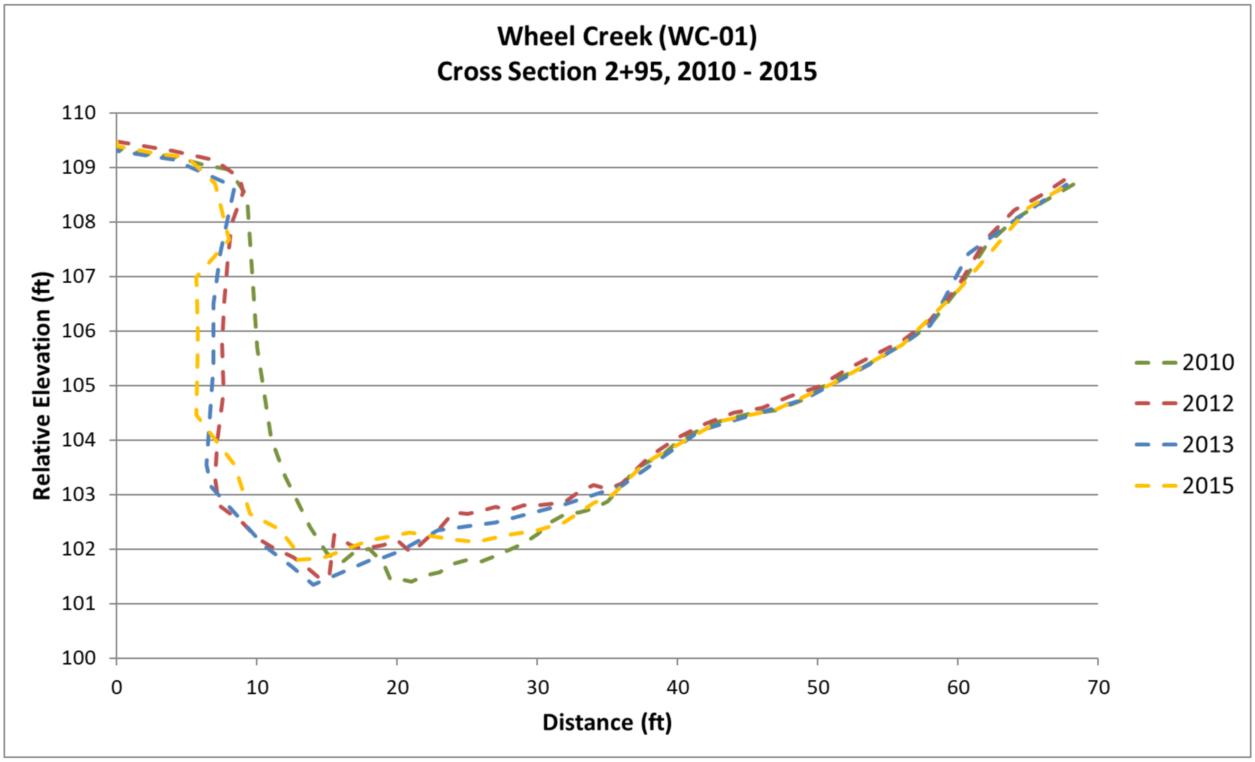

Figure C-9. WC01 Cross-section 2 (Pre-Restoration)

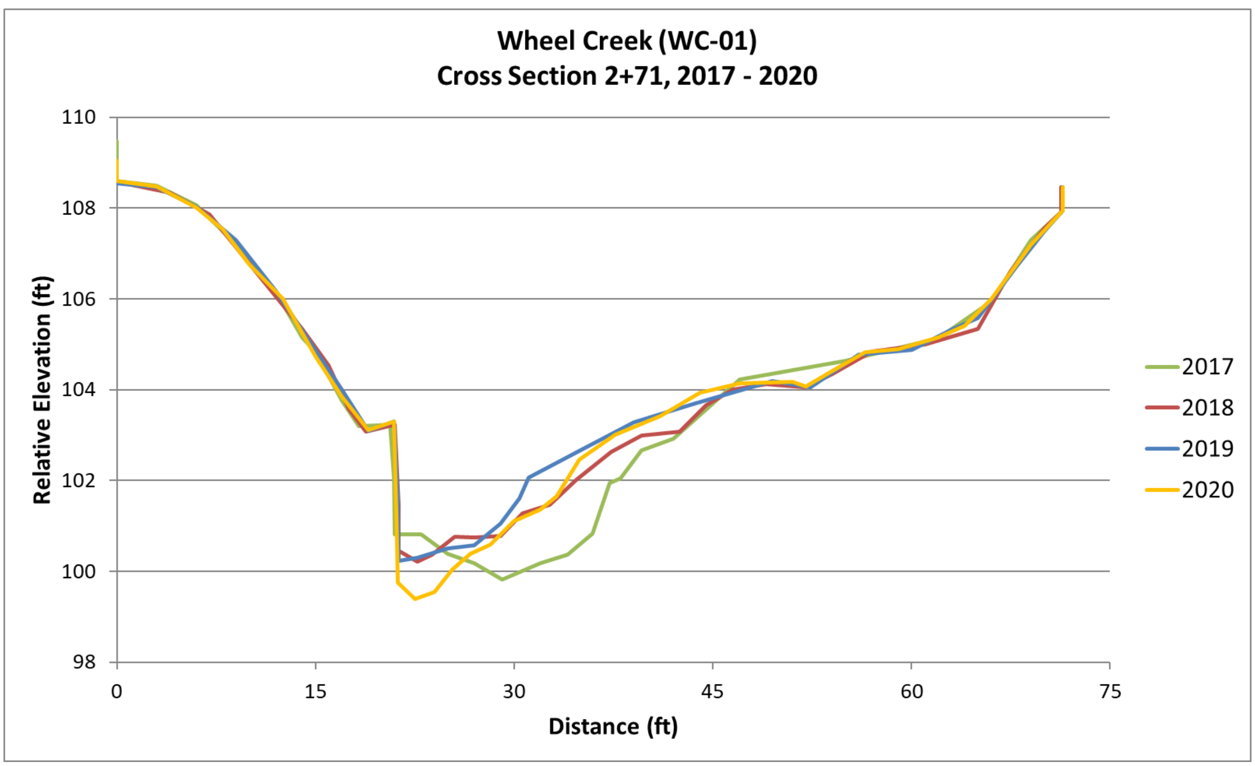

Figure C-10. WC01 Cross-section 2 (Post-Restoration)

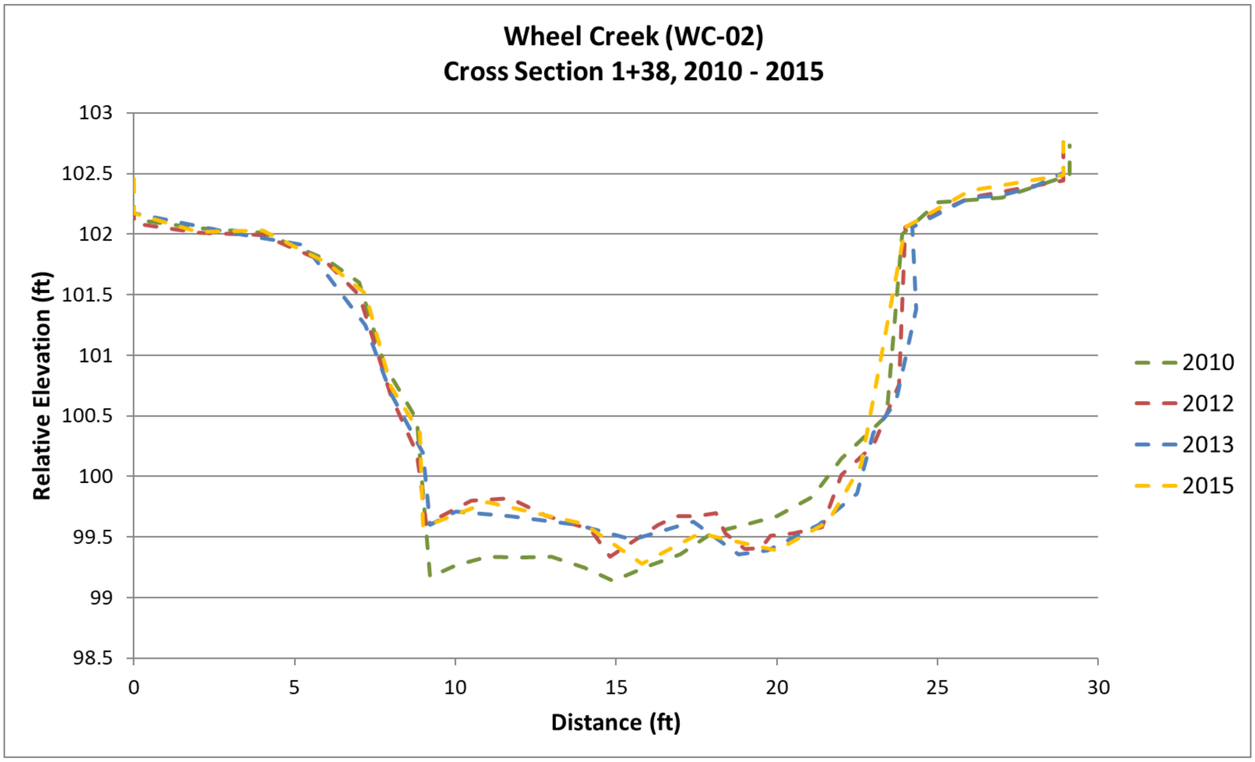

Figure C-11. WC02 Cross-section 1 (Pre-Restoration)

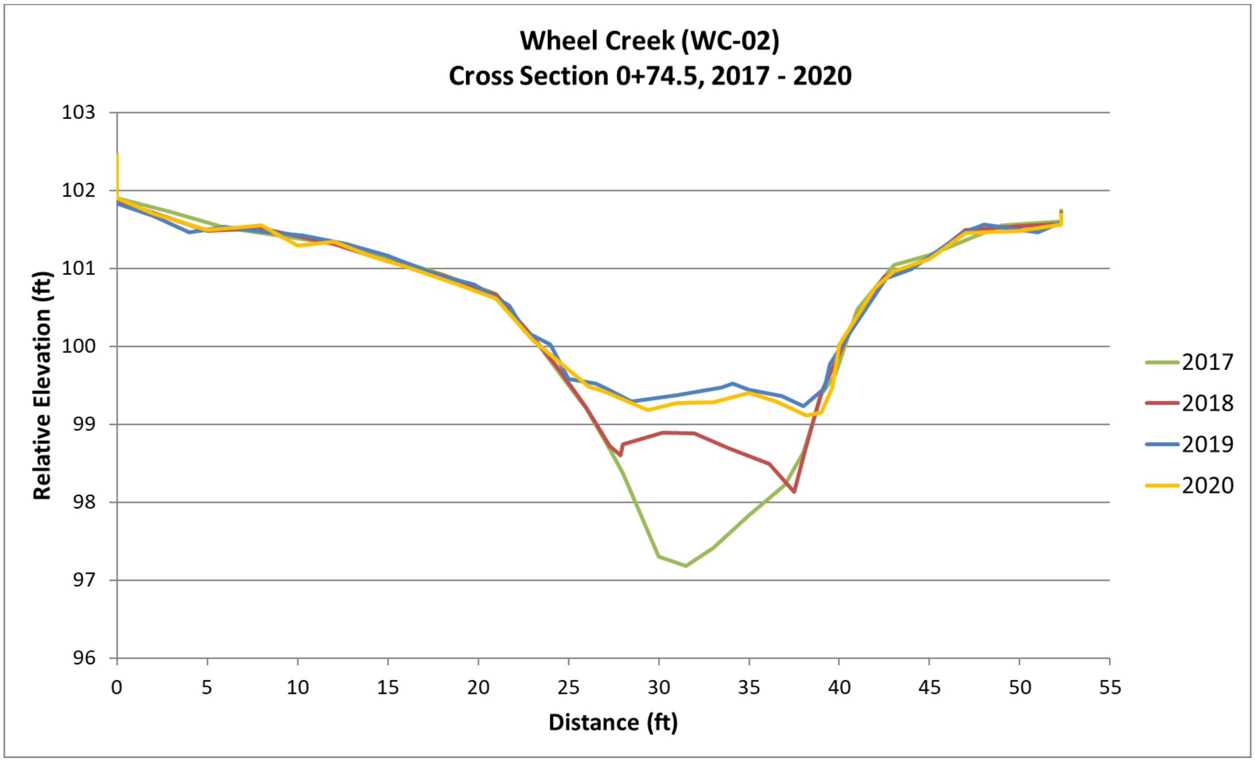

Figure C-12. WC02 Cross-section 1 (Post-Restoration)

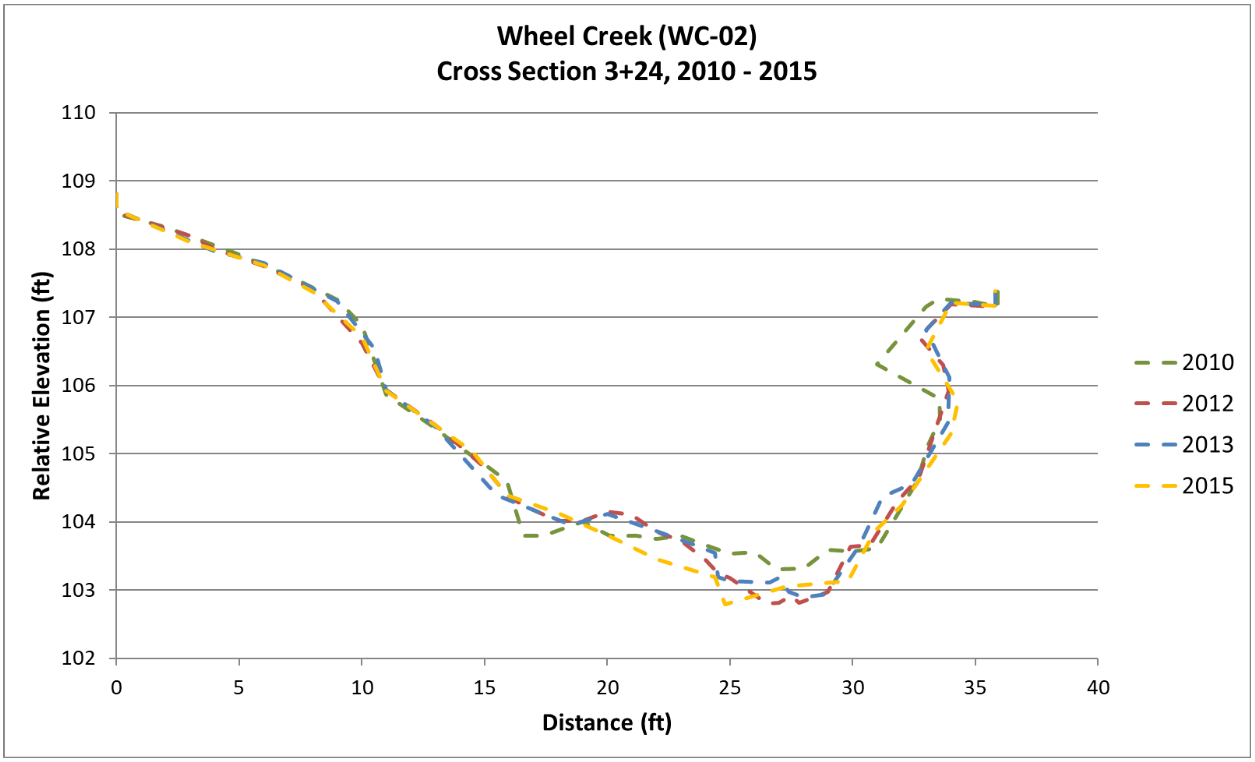

Figure C-13. WC02 Cross-section 2 (Pre-Restoration)

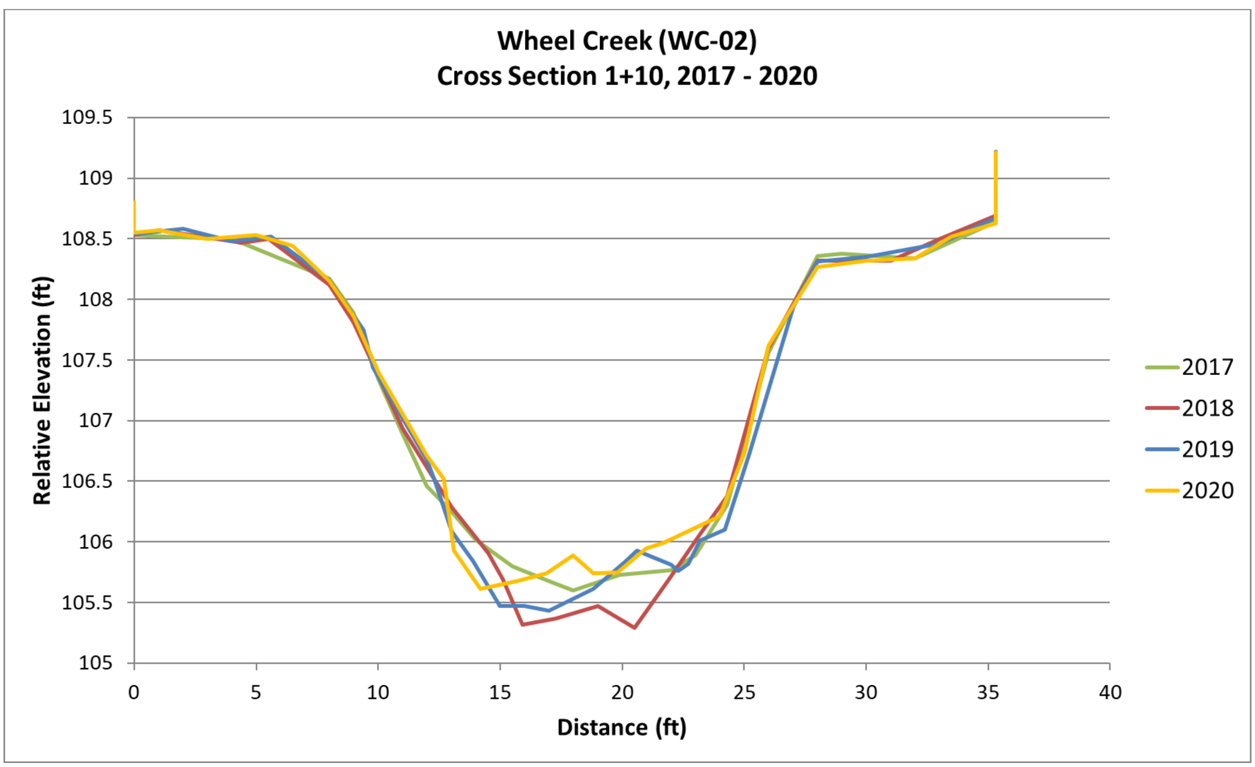

Figure C-14. WC02 Cross-section 2 (Post-Restoration)

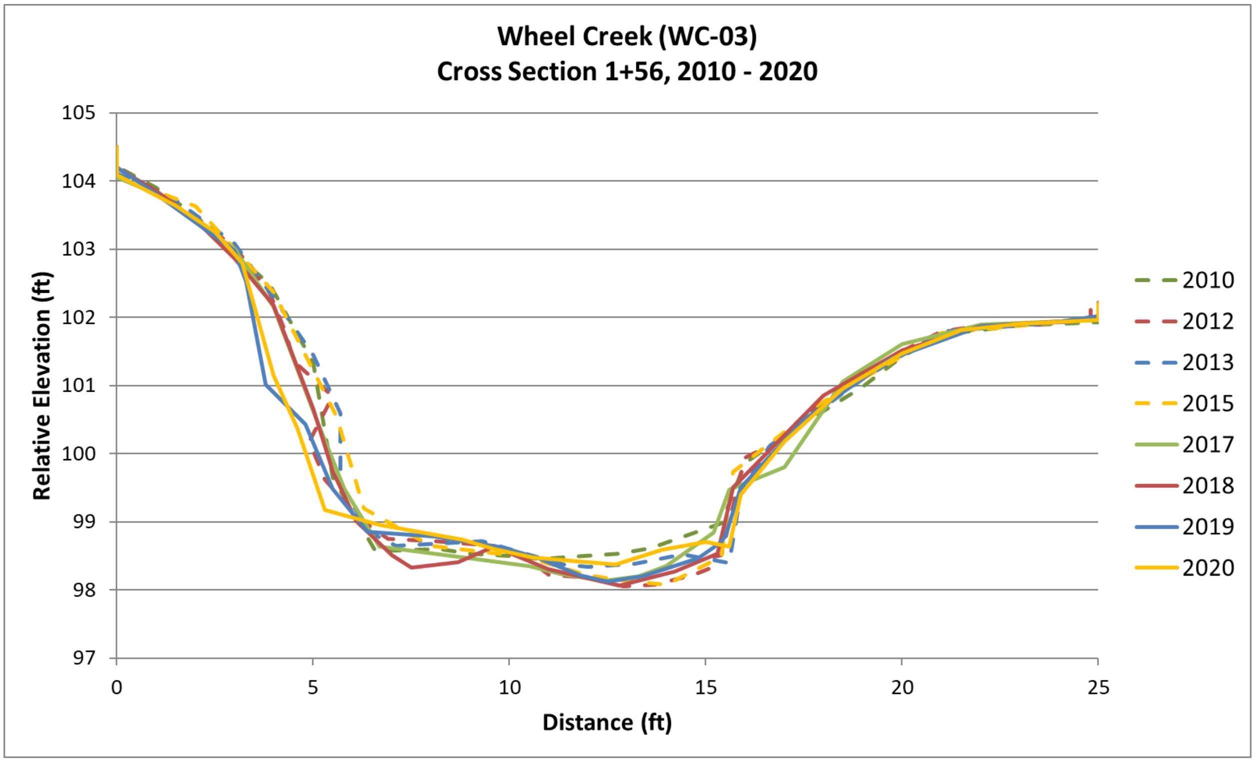

Figure C-15. WC03 Cross-section 1 (Pre- and Post-Restoration)

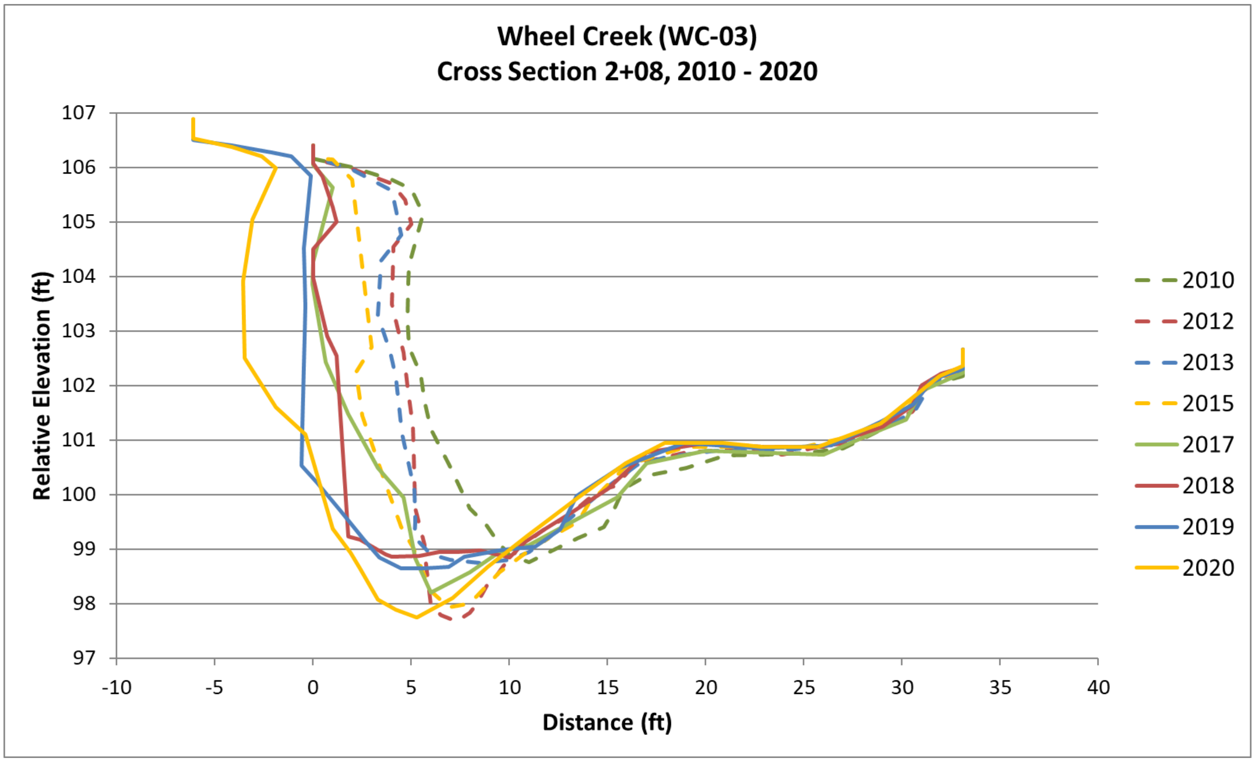

Figure C-16. WC03 Cross-section 2 (Pre- and Post-Restoration)

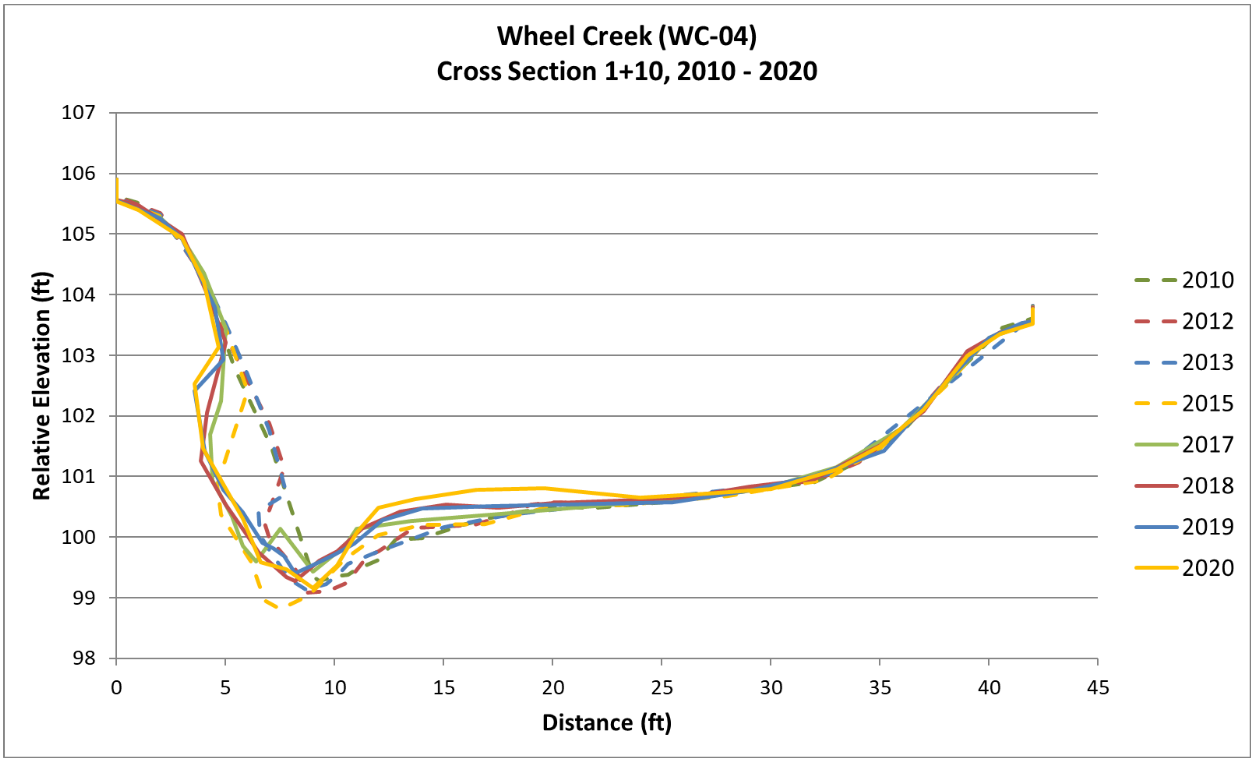

Figure C-17. WC04 Cross-section 1 (Pre- and Post-Restoration)

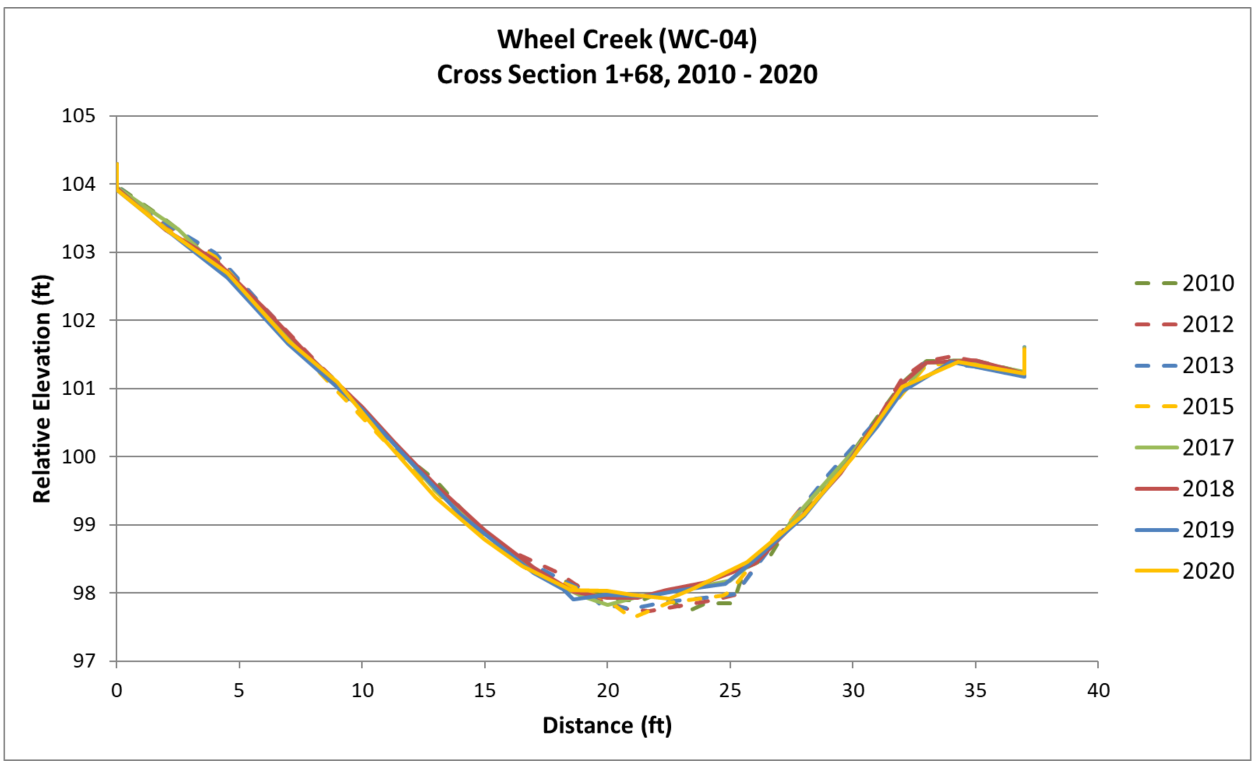

Figure C-18. WC04 Cross-section 2 (Pre- and Post-Restoration)

Table C-3. Particle Size Distribution Pre-Restoration Years 1 – 4, Post-Restoration Years 1 – 4

Year	Riffle Feature Surface			Meander Feature Surface			Reachwide		
	Measure	Size (mm)	Size Class	Measure	Size (mm)	Size Class	Measure	Size (mm)	Size Class
WC01*									
2010	D50	39	very coarse gravel	D50	38	very coarse gravel	D50	44	very coarse gravel
2012	D50	56	very coarse gravel	D50	40	very coarse gravel	D50	51	very coarse gravel
2013	D50	49	very coarse gravel	D50	37	very coarse gravel	D50	55	very coarse gravel
2015	D50	50	very coarse gravel	D50	55	very coarse gravel	D50	42	very coarse gravel
2017	*D50*	*52*	*very coarse gravel*	*D50*	*11*	*medium gravel*	*D50*	*25*	*coarse gravel*
2018	*D50*	*41*	*very coarse gravel*	*D50*	*32*	*very coarse gravel*	*D50*	*47*	*very coarse gravel*
2019	*D50*	*47*	*very coarse gravel*	*D50*	*12*	*medium gravel*	*D50*	*37*	*very coarse gravel*
2020	*D50*	*42*	*very coarse gravel*	*D50*	*25*	*coarse gravel*	*D50*	*32*	*coarse gravel*
2010	D84	120	medium cobble	D84	90	medium cobble	D84	140	large cobble
2012	D84	180	large cobble	D84	77	small cobble	D84	120	medium cobble
2013	D84	130	large cobble	D84	87	small cobble	D84	130	large cobble
2015	D84	160	large cobble	D84	110	medium cobble	D84	150	large cobble
2017	*D84*	*120*	*small cobble*	*D84*	*57*	*very coarse gravel*	*D84*	*90*	*small cobble*
2018	*D84*	*150*	*large cobble*	*D84*	*97*	*medium cobble*	*D84*	*160*	*large cobble*
2019	*D84*	*110*	*medium cobble*	*D84*	*51*	*very coarse gravel*	*D84*	*90*	*small cobble*
2020	*D84*	*110*	*medium cobble*	*D84*	*84*	*small cobble*	*D84*	*93*	*medium cobble*
WC02*									
2010	D50	50	very coarse gravel	D50	45	very coarse gravel	D50	49	very coarse gravel
2012	D50	40	very coarse gravel	D50	33	very coarse gravel	D50	28	coarse gravel
2013	D50	51	very coarse gravel	D50	47	very coarse gravel	D50	40	coarse gravel
2015	D50	36	very coarse gravel	D50	26	very coarse gravel	D50	36	very coarse gravel
2017	*D50*	*26*	*coarse gravel*	*D50*	*4.3*	*very fine gravel*	*D50*	*16*	*medium gravel*
2018	*D50*	*41*	*very coarse gravel*	*D50*	*64*	*small cobble*	*D50*	*27*	*coarse gravel*
2019	*D50*	*51*	*very coarse gravel*	*D50*	*16*	*medium gravel*	*D50*	*22*	*coarse gravel*
2020	*D50*	*82*	*small cobble*	*D50*	*43*	*very coarse gravel*	*D50*	*37*	*very coarse gravel*
2010	D84	98	medium cobble	D84	94	medium cobble	D84	100	medium cobble
2012	D84	80	small cobble	D84	69	small cobble	D84	80	small cobble
2013	D84	88	small cobble	D84	86	small cobble	D84	110	medium cobble
2015	D84	100	medium cobble	D84	100	medium cobble	D84	110	medium cobble
2017	*D84*	*85*	*very coarse gravel*	*D84*	*19*	*medium gravel*	*D84*	*62*	*very coarse gravel*
2018	*D84*	*120*	*medium cobble*	*D84*	*130*	*large cobble*	*D84*	*110*	*medium cobble*
2019	*D84*	*110*	*medium cobble*	*D84*	*64*	*small cobble*	*D84*	*76*	*small cobble*
2020	*D84*	*150*	*large cobble*	*D84*	*100*	*medium cobble*	*D84*	*80*	*small cobble*
WC03									
2010	D50	33	very coarse gravel	D50	8.7	medium gravel	D50	28	coarse gravel
2012	D50	27	coarse gravel	D50	15	medium gravel	D50	23	coarse gravel
2013	D50	27	coarse gravel	D50	29	coarse gravel	D50	35	very coarse gravel
2015	D50	36	very coarse gravel	D50	7.2	fine gravel	D50	26	coarse gravel
2017	*D50*	*26*	*coarse gravel*	*D50*	*17*	*medium gravel*	*D50*	*16*	*medium gravel*
2018	*D50*	*26*	*coarse gravel*	*D50*	*14*	*medium gravel*	*D50*	*22*	*coarse gravel*
2019	*D50*	*45*	*very coarse gravel*	*D50*	*23*	*coarse gravel*	*D50*	*22*	*coarse gravel*
2020	*D50*	*36*	*very coarse gravel*	*D50*	*12*	*medium gravel*	*D50*	*31*	*coarse gravel*
2010	D84	74	small cobble	D84	72	small cobble	D84	75	small cobble
2012	D84	59	very coarse gravel	D84	43	very coarse gravel	D84	72	small cobble
2013	D84	68	small cobble	D84	59	very coarse gravel	D84	130	large cobble
2015	D84	85	small cobble	D84	30	coarse gravel	D84	69	small cobble
2017	*D84*	*59*	*very coarse gravel*	*D84*	*61*	*very coarse gravel*	*D84*	*50*	*very coarse gravel*
2018	*D84*	*69*	*small cobble*	*D84*	*50*	*very coarse gravel*	*D84*	*51*	*very coarse gravel*
2019	*D84*	*88*	*small cobble*	*D84*	*70*	*small cobble*	*D84*	*80*	*small cobble*
2020	*D84*	*77*	*small cobble*	*D84*	*44*	*very coarse gravel*	*D84*	*71*	*small cobble*
WC04									
2010	D50	30	coarse gravel	D50	18	coarse gravel	D50	22	coarse gravel
2012	D50	36	very coarse gravel	D50	15	medium gravel	D50	24	coarse gravel
2013	D50	33	very coarse gravel	D50	1.5	very coarse sand	D50	36	very coarse gravel

Table C-3. Continued

Year	Riffle Feature Surface			Meander Feature Surface			Reachwide		
	Measure	Size (mm)	Size Class	Measure	Size (mm)	Size Class	Measure	Size (mm)	Size Class
WC04									
2015	D50	35	very coarse gravel	D50	8.3	medium gravel	D50	28	coarse gravel
2017	*D50*	*43*	*coarse gravel*	*D50*	*12*	*medium gravel*	*D50*	*21*	*medium gravel*
2018	*D50*	*33*	*very coarse gravel*	*D50*	*1.9*	*very coarse sand*	*D50*	*17*	*coarse gravel*
2019	*D50*	*27*	*coarse gravel*	*D50*	*1.2*	*very coarse sand*	*D50*	*23*	*coarse gravel*
2020	*D50*	*49*	*very coarse gravel*	*D50*	*20*	*coarse sand*	*D50*	*22*	*coarse gravel*
2010	D84	80	small cobble	D84	87	small cobble	D84	71	small cobble
2012	D84	64	small cobble	D84	70	small cobble	D84	76	small cobble
2013	D84	57	very coarse gravel	D84	64	small cobble	D84	79	small cobble
2015	D84	66	small cobble	D84	24	coarse gravel	D84	72	small cobble
2017	*D84*	*99*	*small cobble*	*D84*	*26*	*coarse gravel*	*D84*	*68*	*very coarse gravel*
2018	*D84*	*70*	*small cobble*	*D84*	*32*	*very coarse gravel*	*D84*	*47*	*very coarse gravel*
2019	*D84*	*80*	*small cobble*	*D84*	*29*	*coarse gravel*	*D84*	*81*	*small cobble*
2020	*D84*	*92*	*medium cobble*	*D84*	*58*	*very coarse gravel*	*D84*	*75*	*small cobble*

*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)

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